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Influence of Flooding, Soil Ph, Copper, and Zinc on Growth and Chemical Composition of Rice Plants.

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INFLUENCE OF FLOODING, SOIL pH, COPPER, AND ZINC ON GROWTH AND CHEMICAL COMPOSITION OF RICE PLANTS

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TABLE OF CONTENTS

LIST OF TABLES

Table		Page

Table Page

Table | Page

LIST OF FIGURES

Figure Page

Figure		Page

Figure | Page

Figure Page

ABSTRACT

Investigations were conducted in the greenhouse, field, and laboratory to evaluate eight different chemical methods for estimating the availability of Cu in air-dried and flooded soils, and to determine the influence of flooding, soil pH, and applications of Cu and Zn on the growth and chemical composition of rice(*Oryza sativa L.* cultivar Saturn) plants grown on selected soils in Louisiana.

DTPA-TEA extractant generally removed smaller amounts of Cu and Zn and larger amounts of Mn and Fe from flooded soils than from air-dried soils. In general, levels of soil Ca, Mg, and K were significantly correlated with extractable Cu. No significant relationships were found between extractable Cu and soil pH or soil organic matter content.

The DTPA-TEA, pH 7.3, 0.1*N* HCl, and 1*N* NH_4OAc, pH 4.8 extractable Cu were significantly related to the concentration of Cu in rice tissue. A significant negative correlation was found between Cu concentration in rice tissue and soil organic matter content. Multiple regressions consisting of extractable Cu and soil organic matter accounted for over 53% of the variations in predicted concentration of Cu in rice tissue. In general, Cu uptake by rice plants was significantly correlated with extractable Cu.

Flooding the Lafitte muck significantly increased the production of dry matter, total leaf chlorophyll content, and the concentrations of Cu, Fe, and P, and significantly decreased the concentrations of Zn, Mn, Ca, and K in rice tissue. The dry matter production and nutrient concentration and uptake by rice plants were greatly reduced when soil pH was adjusted to over 5.9 by application of $CaCO_3$. The concentrations of Cu, Zn, Mn, and Fe in rice tissue were significantly higher at pH 4.8 than at pH 4.2. The application of 5ppm of Cu significantly increased the production of dry matter, total leaf chlorophyll content, and concentrations of Cu, Fe, and Ca, and significantly decreased the concentrations of P and K in rice tissue.

The concentration of Cu in the tissue of rice plants grown on Lafitte muck without applied Cu tended to be lower under flooded conditions than under nonflooded conditions. When Cu was applied, it was significantly higher under flooded conditions. The soil pH levels did not significantly influence the concentration of Cu in plants grown on the soil that did not received Cu. Application of Cu resulted in a significantly higher Cu concentration in rice tissue at pH 4.8, 5.4, and 5.9. The concentration of Zn in rice tissue was significantly increased at pH ≤ 5.4, and decreased at pH ≥ 5.9 by application of Cu.

Cu and Zn applied to Crowley silt loam under field conditions did not significantly influence the grain yields, although consitently higher yields were obtained on plots that received Cu and Zn in each of the two years. The application of Cu significantly increased the leaf concentrations of Cu and Zn. Applied Zn significantly increased the concentration of Zn, but did not significantly influence the concentration of Cu in rice leaves at first joint.

The data obtained from laboratory, greenhouse, and field investigations indicate that there is not a critical need for supplimental Cu fertilization of rice on the mineral soils. The data suggest that Cu may be beneficial to rice plants growing on soils that contain more than approximately 4% of organic matter and less than 0.2 ppm of DTPA-TEA extractable Cu.

INTRODUCTION

Cu is an essential micronutrient element for the plants(Sommer, 1931; Lipman and MacKinney, 1931). Cu is generally absorbed by the plant as the divalent cation, Cu^{2+}. Cu is an important constituent of several oxidative enzymes in the plant cells as a prosthetic group(Uritani, 1975). Cu appears to participate in respiration and photosynthesis, and in the synthesis or stability of chlorophyll and other pigments. Cu also seems to be involved in protein and carbohydrate metabolisms.

The primary causes of Cu deficiency are inherently low amounts of total Cu present and low solubility and availability of Cu in the soil. The deficiency occurs more often due to insufficient availability than to low total Cu content in the soil.

There are many factors influencing the availability of Cu in soils, such as soil pH, organic matter, moisture, soil texture, presence of other metallic ions, the crop species to be grown, and cultural practice. Cu deficiency has frequently been associated with soils high in organic matter. Many workers have reported Cu fixation by organic matter. Of further significance is the fact that as cropping becomes more intensive and growers strive for higher yields, any factor or practice which tends to reduce the availability of Cu may result in occurrence of Cu deficiency on certain soils. This induced Cu deficiency emphasizes the need to maintain nutrient balance for maximum growth.

Various extractants have been proposed and used for estimating the availability of Cu in soils. However, the suitability of a particular method or extractant may be limited because of wide diversities in soil properties and plant characteristics. Conditions in flooded soils differ greatly from those in well-drained soils. The physical, chemical, and biological changes brought about by flooding have a marked effect on the behavior of essential plant-nutrient elements and the subsquent growth of rice plants. Rice plants also differ from other crops in the requirement for Cu and in the ability to absorb Cu from the soil. Thus, it is necessary that suitable reagents should be evaluated for extracting Cu from flooded soils.

The influence of micronutrient applications on growth and nutrition of the rice plant has been receiving increasing attention. Investigations have demonstrated that Zn contents of some soils in Louisiana are critically low and response to application of Zn has been obtained under certain soils and environmental conditions. Research has also shown that most soils used for rice production contain adequate to high amounts of soluble Mn and Fe. On the other hand, the extractable Cu contents of some of these soils are considered to be relatively low.

A fundamental understanding is needed as to how native and added Cu affect the growth and nutrition of the rice plant under different soil conditions. The objectives of these investigations were as follows:

1) To evaluate eight different chemical methods for extracting Cu from air-dried and flooded soils.
2) To determine the influence of flooding periods on extractable Cu, Zn, Mn, and Fe contents of soils.
3) To determine the effects of four different rates of applied Cu on the production of dry matter and nutrient contents of rice plants grown on the two soils high in organic matter under greenhouse conditions.
4) To determine the influence of flooding, soil pH, and application of Cu on growth and chemical composition of rice plants grown on Lafitte muck under greenhouse conditions.
5) To determine the effects of applications of Cu and Zn on grain yields and chemical composition of rice plants grown on Crowley silt loam under field conditions.

REVIEW OF LITERATURE

A. Factors Affecting the Availability of Cu in soils.

1. Soil reaction(pH)

Soil reaction(pH) is one of the most important properties of the soil solution. Soil reaction influences the growth of all plants and microorganisms as well as the chemical and physical properties of soil(Ponnamperuma, 1977).

A number of researchers have studied the effects of soil reaction on the availability of Cu in soils. In general, increasing the soil pH decreases the solubility and availability of Cu to plants. Peech(1941) found that the amount of 1*N* NaCl extractable Cu in a Norfork fine sand decreased as the soil reaction was increased from pH 3.1 to 8.0. Percival, Josselyn, and Beeson(1955) reported that lime or high rates of fertilizers reduced Cu absorption by red clover grown on soils in New Hampshire.

According to Reuther(1957), soils retain Cu tightly in the range of pH 7.0 to 8.0, less securely at pH 6.0 and progressively less at lower pH levels. Lucas(1946) stated that the availability of Cu was dependent upon the soil reaction but it did not normally increase appreciably until the pH decreased below 5.0. Brown and Foy(1964) found that on an acid soil(pH 4.5, 2.5% organic matter), liming to a pH range of 5.2 to 5.5 induced Cu deficiency symptoms in barley. The deficiency was characterized by a rolling of the youngest leaves and a reduced translocation of Ca to these plant parts.

Berger and Pratt(1963) noted that when Cu is applied to soils, that portion which is not chelated by organic matter is probably precipitated as $Cu(OH)_2$ at soil solution pH values above 4.7. Misra and Tiwari(1966) found that an alkaline soil, pH 10.9, retained applied Cu in $CuCO_3$ and $Cu(OH)_2$ forms due to its high $CaCO_3$ content and high pH, while a red acid soil retained less Cu because of its low pH and negligiable $CaCO_3$ content. Pesek(1950) indicated that an increase in Ca saturation of the exchange complex resulted in less Cu in the soil solution. He attributed this to a lack of H ions to displace Cu into the solution.

Truog(1946) showed that maximum availability of Cu occurred between pH 5.0 and 7.0. Similar results were reported by Lutz, Genter, and Hawkins(1972). They reported that among three soil pH levels, average Cu concentration in six maize cultivars was significantly higher at soil pH 5.1 than at pH 3.9 or at pH 6.1, and the greater uptake of Cu was obtained at the higher pH levels. However, Younts and Patterson(1964) reported that in a Hyde soil containing 22.5% organic matter, liming to above pH 5.1 lowered the Cu concentration in wheat plants. Yields were increased by both lime and Cu applications, but yield responses to Cu were better without lime than with lime. It was suggested that the lower Cu response with lime was due to stimulated root growth which enabled plants to extract Cu from a larger zone of soil. Lundblad, et al.(1949) also reported that the Cu content of soil was 35% higher on limed soil, and the Cu concentration of the plants was 26% higher.

Wallace, et al.(1974) reported that Cu concentrations of soybeans and bushbeans were increased by both applications of S and $CaCO_3$. Since Cu levels were higher in some plants with lime-induced chlorosis, high soil pH in combination with organic ligands may have resulted in increased Cu uptake by plants.

Lundblad, et al.(1949) stated that, in practice, the content of $CaCO_3$ and the pH values of the soil would not interfere to a very great extent with plant availability of Cu. The authors stated that a more important consideration was the effect of pH on leaching of Cu. Harmer(1945) reported that a greater response to Cu was obtained on organic soils with naturally low pH values than on slightly acid soils. He speculated that increased availability would result in increased leaching over many years, thus depleting the Cu present in the acid soil.

Neelakantan and Mehta(1961) found a significant negative correlation between the pH of the soils and Cu extracted with 1N NH_4OAc from 64 soils in western India. No significant correlations were found between pH, organic matter, or soil texture and total or available Cu in calcareous soil profiles(Neelakantan and Mehta, 1962).

Grewal, Bhumbla, and Randhawa(1969) reported that available Cu showed a significant negative correlation with pH, and a positive correlation with organic matter. Eswarappa, Naik, and Das(1969) observed significant positive correlations between pH and extractable Cu or Zn in lateritic soils. No significant correlations were found in black soils. Blevins and Massey(1959) failed to show a significant correlation between Cu uptake by millet and soil pH in pot experiments with 34 soils in Kentucky.

2. Organic matter

The effect of organic matter on the behavior of Cu in soils is particularly pronounced. When Cu was first recognized as an essential plant nutrient, workers noted that deficiencies of the element occur on organic soils, especially newly cultivated peat soils, more often than on mineral soils.

The amount of applied Cu required to overcome deficiencies is largely dependent upon the amount of organic matter in soil. Tobia and Hanna(1958) reported that more Cu from applied $CuSO_4$ was retained in a sandy loam containing 2.6% organic-C than in two clay soils with lower contents of organic-C. However, the Cu retained in the sandy loam soil was almost completely extractable with 1N HCl.

According to Eswarappa, Naik, Das(1969), the availability of Cu and Zn in mineral soils increased with a corresponding increase in the content of organic matter up to 5-15%, but further increases in organic matter content rendered these two elements unavailable.

Since Cu deficiency occurs primarily on humus rich soils which reportedly bind Cu very strongly, certain organic complexes may render Cu unavailable. A review of research by Mortensen(1963) has shown that organic matter in soils forms complexes with metals by ion exchange, surface adsorption, and chelation reaction mechanisms.

It has been well established that numerous compounds released when organic matter decomposes are capable of forming stable combinations with metal ions. Some of the metal ions are held as insoluble complexes and are unavailable to plants. The metals in soil that occur in insoluble combinations with organic matter are largely those that are bound to components of the humic fraction, particularly humic acids. On the other hand, many metals that ordinarily would form insoluble precipitates at the pH values found in productive agricultural soils are maintained in solution through chelation. The metals found in soluble complexes are mainly those associated with individual biochemical molecules, such as organic acids. Metal complexes with fulvic acids also have high water solubilities(Stevenson and Ardakani, 1972).

Kanwar(1954) reported that Cu fixation from added $CuSO_4$ was associated with the formation of metal-organic complexes. The Cu content of three Podzol profiles tended to be concentrated in humic fractions of the soils. Added Cu was strongly adsorbed by the humic acid extracts, but was not fixed in plant-unavailable forms. DeMumbrum and Jackson(1956) reported that Cu and Zn saturation of peat fractions resulted in numerous shifts in the double bond regions of the spectra. This was indicative of chelation with C=O and N=O groups.

Schnitzer and Skinner(1965) measured the metal retention capacity of untreated organic matter and of organic matter in which several functional groups were selectively blocked. They found that blocking of either carboxyls or phenolic hydroxyls significantly reduced metal retention. Both groups appeared to act simultaneously with the metal ions by a reaction. Alcoholic hydroxyls did not participated in the organo-metalic reactions.

According to research conducted by Butler(1957), Cu was found to be more tightly complexed by phenolic and carboxylic groups as the pH increases, and once it was complexed it was not readily replaced by equilibrating with other metals. Hodgson, Geering, and Norvell(1965) concluded that as much as 99% of Cu present in the soils may exist in association with organic complexing agents. Goodman and Cheshire(1976) reported that humic acids retained Cu in the form of porphyrin complexes.

3. Clay content

The colloidal fractions of soils play an important role in retaining and releasing Cu to plants. The Cu concentration in the soil solution is influenced by Cu adsorption by soil particles. Pesek(1950) demonstrated that inorganic colloids could influence the availability of Cu. Grimme(1968) also reported that Cu was held very tightly on inorganic exchange sites, denoting low availability to plants.

According to McBride and Mortland(1974), studies of the interaction of exchangeable Cu^{2+} with montmorillonite showed that exchangeable Cu was strongly hydrated, possibly as $Cu(H_2O)_6^{2+}$. Upon air-drying, loss of water forms the interlayer $Cu(H_2O)_4^{2+}$ species. Dehydration of exchangeable Cu^{2+} allows these ions to become imbedded in hexagonal cavities of the silicate structure, or penetrate into empty octahedral positions, thus lowering the layer charge. Cu ions that have migrated to the octahedral layers are not exchangeable. No evidence for specific adsorption was found. The results indicate that the properties of Cu ions on clay surfaces are dependent largely on its strongly held ligand water, and the ion behaves much like other divalent ions on clays. McBride(1976) also reported that the exchange between Na^{+} and Cu^{2+} on smectites showed a large preference for the divalent ion when the Cu^{2+} content of the clay was low. Heterogeneity of exchange sites is suggested to explain its behavior. The Na^{+}/Cu^{2+} ratio of the exchange sites greately influences the hydration properties of the interlayer regions of smectites.

Cole(1943) found that pastures in Western Australia on the kaolinite-geotite phase were higher in Cu than those on the kaolinite-hematite phase. The ability of kaolinite-type clays to adsorb ions introduces some unexpected effects, and raises some interesting questions in regard to Cu release from clayey soils and stream sediments(Payne and Pickering, 1975). They reported that the extent to which Cu^{2+} species were removed from aqueous solution by kaolinite clay suspensions varied with solution pH, the nature of any ligand present, and the order of contact of the species.

The research results reported by several investigators show that Cu concentration in soils is related to Cu concentration in the parent material and percentage clay in the soil horizon(Bleeker and Austin,1970; Follett and Lindsay, 1971; Khan, 1979; Shuman, 1979). Follett and Lindsay(1971) observed that available Cu increased with both total Cu and clay content in 37 soils in Colorado. In general, clay is higher in total or extractable Cu than is the sand-silt fraction(Khan, 1979; Shuman, 1979).

In contrast, clay content of soil was not significantly related to available Cu, while a highly significant correlation was found between total Cu and clay and silt content(Neelakantan and Mehta, 1961). In addition, a significant correlation was not found between available Cu and the clay content of three soil groups studied by Eswarappa, Naik, and Das(1969).

Ufkes and McBride(1978) studied the effect of added organic acids on the adsorption of Cu^{2+} and Cd^{2+} on montmorillonite and a hydrous-alumina gel. They found that the acids formed complexes with Cu^{2+} and Cd^{2+}, and inhibited metal adsorption on the clay. The order of inhibition of Cu^{2+} adsorption on montmorillonite was fulvic acids > phthalic acids > salicylic acids > no acid. However, fulvic acids enhanced the adsorption of Cu^{2+} on the amorphous alumina gel, while salicylic acids and phthalic acids slightly inhibited adsorption. They concluded that Cu^{2+} probably binds to the alumina surface via bonds with surface hydroxyl groups, i.e., $Al-O-Cu^{+}$, and not as an organic metal chelate.

4. Flooding

Conditions in waterlogged soils differ from those in well-drained soils. Changes in oxidation/reduction potential and pH brought about by flooding have a marked effect on the behavior of several important plant nutrients and on the growth and yield of rice, the crop most frequently grown under submerged soil conditions.

These two important physiological parameters, redox potential and pH, are important factors affecting chemical transformations, mobilization/immobilization, and the availability of metals in soils and sediments (Gambrell, Khalid, and Patrick, 1976).

According to the fractionation scheme of McLaren and Crawford(1973), Cu may be present in soils as: (1) soil solution and exchangeable Cu, (2) Cu weakly bound to specific sites, (3) organically bound Cu, (4) Cu occluded by oxides, or (5) residual Cu mainly in the clay lattice structure. It is suggested that the Cu concentration in solution is controlled by equilibria involving specifically adsorbed Cu and that most of the available Cu reserves are organically bound.

Metals weakly adsorbed to the solid minerals or organic colloidal phase are strongly influenced by redox potential and pH. Development of reducing conditions will result in instability of colloidal hydroxides, likely causing release of some adsorbed or coprecipitated trace metals. A review of research by Ponnamperuma(1977) indicates that Fe(III) oxides and Mn(IV) oxides present in soils may release Cu^{2+} under flooded conditions, and the release may be attributed to surface reactions brought about by reduction or to the increased pH accompanying reduction.

In strongly reduced environments, the formation of stable, insoluble metal sulfide precipitates is important in limiting the mobility and bioavailability of most metals(Krauskopf, 1956). Sanchez and Lee(1973) demonstrated that Cu was immobilized by sulfide precipitation after being released from hydrous metal oxides. Engler and Patrick(1975) determined the solubility of labeled sulfur and found that metal sulfides of Mn, Fe, Zn, Cu, and Hg were stable in flooded soils. Rice plants grown on strongly reduced soils that received applications of sulfides of these heavy metals were found to take up tagged sulfur. This indicated that oxidation occurred in the rhizosphere and increased the availability of the metals and sulfur to the growing rice roots.

According to Ponnamperuma(1977), the concentration of Cu in the solutions of flooded soils is several orders higher than those that could be accounted for by the solubility of CuS or Cu_2S. But he noted that the concentration of water-soluble Cu in the soil decreases upon flooding despite desorption from Fe(III) and Mn(IV) oxide hydrates. This may be due in part to pH increase.

Changes in humic substances influenced by changes in oxidation-reduction intensity upon flooding may influence fixation of Cu. It is possible that humic materials in reduced environments are characterized by large molecular weights and greater structural complexity, thus increasing metal retention capacity and metal bonding stability of insoluble humic materials. Mercer and Richmond(1970) showed that the availability of organically bound Cu depended not only on the concentration in the soil solution but also on the forms in which the Cu occurred. In the soil solution, Cu complexes of molecular weight 1,000 were much more available to plants than those of molecular weight in excess of 5,000.

5. Nutrient interactions

Cu is known to be interrelated with other nutrient elements in plants. Furthermore, there is evidence indicating that the uptake of Cu is influenced by the ratio of the Cu to other elements in the rooting medium as opposed to the absolute amounts present.

a. Cu x N interaction On Cu deficient soils, high N concentrations in plants are associated with more pronounced Cu deficiency symptoms(Fleming and Delaney, 1961; Chaudhry and Loneragan, 1970). Chaudhry and Loneragan(1970) reported that in pot experiments on acid loamy sand, Cu and Zn had no effect on vegetative or grain yields of wheat in the absence of applied N. Application of N with or without Cu and Zn increased growth 5 to 8 fold. However, without Cu, N application induced slight Cu and Zn deficiencies after 80 days and severe Cu deficiency at maturity. The deficiencies depressed vegetative growth and delayed maturity. At maturity the Cu deficiency increased straw yields and depressed grain yields.

De, et al.(1974) stated that the addition of 2% NH_4Cl or NH_4NO_3 increased Cu adsorption by samples of alluvial, black, hill, red, and laterite soils more than the addition of 4% of these two compounds or the additions of 2 and 4% of $(NH_4)_2SO_4$. Kühn and Judel (1972) reported that in a pot experiment with a very acid sandy soil, application of 50 kg/ha of $CuSO_4$ increased oat yields compared with $CuSO_4$ at 5 kg/ha when a high rate of N was applied as $Ca(NO_3)_2$, but was only slightly more effective when N was applied as $(NH_4)_2SO_4$.

Cheshire, DeKock, and Inkson(1967) reported that with or without Cu, adding NO_3 or NH_4 - N to peat increased Cu uptake by oats. The NH_4-N treatment without Cu was particularly effective in increasing Cu uptake and a greater proportion of the total Cu accumulated in the grain. Tiwari and Kumar(1976) reported that available Cu content of alluvial, peaty, and red soils was not significantly affected by incubation with N, P, K, or NP at standard rates.

<u>b. Cu x P interaction</u> Heavy or prolonged use of phosphate fertilizers may interact with Cu in soils and within plants. Jamison(1943) reported that moderate amounts of superphosphate increased the solubility of Cu in Norfork fine sand and may have slightly repressed the solubility of Zn. Pot studies by Reuther and Smith(1954) have shown that additions of tricalcium phosphate to virgin sandy soils reduced the severity of

harmful symptoms induced by a toxic rate of added Cu. Bingham and Garber(1960) measused significant decreases in the concentration of Cu in sour orange seedlings as the rate of P increased from 50 to 450 ppm P, regardless of the source used.

According to Locascio, Everett, and Fiskell(1968), the P concentration increased and the Cu concentration decreased in watermelons as P application levels increased. Without the addition of Cu, this reduction in Cu uptake decreased fruit yields as the rate of P was increased. Watermelon yields increased with applications of P from ordinary superphosphate, ammoniated superphosphate, and concentrated superphosphate when Cu was applied. Cu uptake and yields were reduced at all levels of applied Cu when diammonium phosphate was used as the source of P.

Spencer(1966) reported that high applications of P reduced Cu concentrations in leaves and roots of citrus seedlings at four levels of applied Cu from 0 to 250 ppm. When applied Cu had reached toxic levels, applied P reduced Cu toxicity. These excessive amounts of Cu markedly decreased P uptake, and subsequently depressed yields. He concluded that one factor in yield depression may have been the inability of seedlings to utilize P at high Cu levels.

Hulagur, Dangarwala, and Mehta(1975) observed variation in the availability of Zn, Cu, and P due to their varying rates of application on a loamy soil, pH 7.4. They found that each of the three elements individually suppressed the availability of the other two. It was concluded that P fertilizer should be supplemented with Zn and Cu to overcome P-induced deficiencies, especially when the P content in the soil is marginal.

The increased severity of Cu deficiency observed when P is applied to oats, growing on a peat medium of low Cu content, may be due to more effective utilization of N in the synthesis of proteins with which Cu may be associated(DeKock, Cheshire, and Hall, 1971).

c. Cu x Fe interaction A high level of Cu prevents uptake and translocation of Fe, thus increasing the probability ot Fe chlorosis(Chapman, Liebig, and Vanselow, 1939; Reuther and Smith, 1954; Spencer, 1966). Willis and Piland(1936) found that corn grown on unproductive peat became chlorotic upon the application of $CuSO_4$. The leaves developed a green color after foliar application of a 1% solution of ferrous sulfate.

Moore, et al.(1957) observed that growth of lettuce at any one level of Cu was affected by Fe supply. The toxic effects of Cu at high levels of supply were decreased by additions of Fe, but the adverse effect of excess Cu was never completely overcome by Fe. Chino and Mitsui(1967) reported that rice plants grown for two months at a high level of Cu and then transferred to solutions containing ^{59}Fe, did not show chlorotic symptoms. Growth was markedly depressed and the tops contained decreased Fe concentrations.

A solution culture of rice plants grown by Dokiya, Owa, and Mitsui(1968) showed that increasing the concentration of ^{59}Fe in the medium suppressed ^{64}Cu absorption. Meanwhile Cu showed no inhibitory effect on Fe absorption by the plants, but rather an accelerating effect was observed. On the other hand, in barley plants ^{59}Fe showed neither inhibitory nor accelerating effect on Cu absorption whereas Cu apparently inhibited Fe absorption.

Cheshire, DeKock, and Inkson(1967) reported that uptake and concentration of Cu in oats were reduced by applied Fe only where Cu had been added to peat. Applied Cu depressed the Fe concentration in oats not only with Fe but also without applied Fe. Cu and Fe amendments caused increases in yields of oats, but neither element was effective alone.

Salardini and Murphy(1977) studied the effects of Fe sources and levels of Fe, and reported that increasing rate of Fe-EDDHA(ethylendiamine di-(O-hydroxy) phenyl-acetic acid) did not show an appreciable effect on DTPA-extractable Cu in the normal soils, whereas in the deficient soils, there was a decrease in Cu dissolution. A high rate of Fe-LS(lignosulfate) increased Cu extraction in both soils. In deficient soils, Fe-PF (polyflavinoid) behaved similar to Fe-LS, but in normal soils there was a sharp decrease in the amount of Cu extracted at high rate of Fe.

d. Cu x Zn interaction Lucas(1945) reported that Zn applied to organic soil increased growth of plants where Cu was present in adequate amount. He also found that the toxic effects of Zn were alleviated by application of Cu. Gilbey, Greathead, and Cartrell(1970) reported that if an excessive rate of Zn was applied, it aggrevated Cu deficiency in wheat and barley. Younts (1964) also reported that Zn tended to decrease the level of Cu in the plants.

Chaudhry, et al.(1973) observed in pot experiments, that the application of Cu increased the Cu content of the plants without affecting the Zn content. Zn application increased the Zn content but decreased the Cu content. Similar effects were also reported by Kausar, et al.(1976). They observed that applied Zn depressed

Cu uptake, but Cu generally had little effect on Zn uptake by rice plants.

Schmid, Haag, and Epstein(1965) reported that Cu inhibits Zn absorption by excised roots of wheat in the presence of low concentrations of Ca salt. In the presence of high concentration(50 mM) of Ca, Chaudhry and Loneragan(1972) observed a strong interaction on Zn absorption by Cu. The effect of Cu on the relationship between the reciprocal of the Zn concentration and the reciprocal of the rate of Zn absorption indicated that Cu inhibits Zn absorption by competition with Zn at the absorption sites.

Honma and Hirata(1974) reported that Cu concentration of rice was increased by Zn.

e. Cu x Mn interaction Lucas(1945) reported that the addition of $CuSO_4$ did not affect the Mn content of plants growing in soils containing adequate amounts of Cu. Ohki(1975) reported that evidently Cu concentration of cotton leaf blades was not influenced by a wide range of Mn concentrations.

Butler(1957) reported that Cu increased Mn uptake as long as there was no Cu toxicity. Robertson, Thompson, and Martin(1973) stated that Cu application increased Mn uptake. The researchers stated that a lack of Cu probably reduces the uptake of Mn. However, the interaction between Cu and Mn was not significant.

Dokiya, Owa, and Mitsui(1968) observed that the effect of Mn on Cu absorption was inhibitory in both rice and barley plants. But no correlation was obtained between the concentration of Mn and the extent of the inhibitory effect. Rhyu(1977) found a significant negative correlation between Cu concentration and Mn concentration in rice leaf blades in pot experiments. Itohara and Tateya(1965) reported that application of Cu in irrigation water inhibited the absorption of Mn and Fe.

B. The Functions of Cu in Plant Growth

The functions of Cu in plant growth are varied and complex. They are not all completely understood and evidence concenrning some functions is inconclusive.

Cu is an important constituent of several important plant enzymes contained in plant cells. Research results indicate that Cu acts as an electron carrier in enzymatic actions. Various kinds of proteins have the capacity to bind Cu. Furthermore, it has been discovered that some particular proteins contain Cu as a prosthetic group (Uritani, 1975). The Cu binding proteins(enzymes) have functions such as catalysis, absorption, or transport. Probably Cu participates in the substrate binding of the enzymes, and directly or indirectly, in their selective catalysis.

The rate of photosynthesis is lower in Cu deficient plants and Cu is concentrated in the chloroplasts of the leaf. Neish(1939) found that about 70% of the total Cu in the leaf was bound in these organells. Conn and Stumpf(1972) reported that Cu is a constituent of the chloroplast protein called plastocyanin. The protein may be one member of the electron transport system, which participates in the photoreduction of H_2O, leading to the production of $NADPH_2$ and ATP, and plays a role in the electron transport chain linking the two photochemical systems.

A number of investigators have reported that Cu may play a part in the synthesis or the stability of chlorophyll and other pigments, although the mechanism is not clear. Orth, Wickwire, and Burge(1934) reported 4.6 times as much chlorophyll in leaves of orange trees that had been fertilized with $CuSO_4$ as compared with those of untreated trees. The trees without Cu showed very little growth as compared with good growth of trees with the element. Agrawal and Pandey(1972) reported that a preplanting soil application of 12.5 kg/ha $CuSO_4$ plus 12.5 kg/ha sprayed after 40 days gave the highest chlorophyll content of wheat and produced a 73% increase over the control. A preplanting application or spray of 25 kg/ha alone was not beneficial.

Anderssen(1932) demonstrated the protective effect of Cu against the destruction of chlorophyll. He reported that after dark treatment for a week, wheat plants in the solution to which Cu had been applied were distinctlly greener than those without Cu. Bergman and Truran(1937) reported 15% more chlorophyll in the leaves of cranberry plants sprayed with Bordeaux mixture than in the leaves of unsprayed plants. In the fall, the chlorophyll content in treated plants decreased slower than in unsprayed plants.

Stotz, Harrer, and King(1937) found that catalytic effects of certain plant juices on the oxidation of ascorbic acid were due in part to Cu-protein catalysts. Kubowitz(1937) purified a Cu-protein(a polyphenol oxidase) from potato juice.

The reactions brought about by ascorbic acid oxidases and polyphenol oxidases(triosinases), involve both a reduction of O_2 and a hydration by means of the reaction, $Cu^{2+} \rightleftharpoons Cu^{+}$, the latter being oxidized by O_2. Brown and Foy(1964) reported that Cu deficient leaves of barley exhibited lower ascorbic acid oxidase activity and contained less Cu and Fe and more P than healty leaves. The nutrient distribution in barley appears to be associated with the Cu-dependent oxidative metabolisms. Ascorbic acid may participate in the maintenance of the oxidation-reduction potential in plant cells at an appropriate value. Ascorbic acid oxidase may be useful in regulatiing the ratio of ascorbic acid concentration to that of dehydroascorbic acid in plant cells(Uritani, 1975).

Further evidence of a relationship between ascorbic acid and P metabolism was found by James, Heard, and James(1944). They showed that additions of ascorbic acid and hexosediphosphate to barley sap increased the loss of hexosediphosphate and the gain of unhydrolyzed esters(triosephosphates). The additions of hexosediphosphate caused O_2 concumption only if ascorbic acid was present.

Polyphenol oxidases take part in the catalysis of oxidation of O-diphenol(or polyphenol) to O-quinone in the presence of O_2. Accumulation of O-quinone may give rise to polymerization whereby dark brown melanin compounds are formed.

Cu also appears to participate both in protein and carbohydrate metabolisms. Possingham(1956) showed that protein synthesis was disturbed in Cu deficient plants, and there was a build up of soluble amino-N compounds. Brown, Tiffin, and Holmes(1958) reported that when wheat plants received sufficient Cu, there was a large decrease in the content of organic acids and simultaneously large increase in the sugar content. Such changes were not observed in Cu-deficient plants. Plants supplied with Cu accumulated less asparagine and aspartic acids than did Cu-deficient plants.

Yates and Hallsworth(1963) studied the effects of varying levels of Cu on soluble amino acids, carboxylic acids, and sugar in subterranean clover, and reported that there was an increase in glutamic acid, α-alanine, and γ-amino-n-butyric acid within a day of increasing the Cu supply in the nodules. The rate of incorporation of ^{14}C from glucose into soluble amino acids and proteins of isolated nodules was roughly proportional to the Cu supply.

C. Cu Deficiency and Toxicity of rice

Crops differ in their sensitivities to Cu deficiency or toxicity. They vary in their requirements for this micronutrient element and in their abilities to extract it from insoluble combinations in the soil.

Research results from soil and waterculture experiments by Tsutsumi and Fujiwara(1966) indicated that rice plants are more resistant to Cu deficiency and more susceptible to excess Cu than are barley plants. The Cu content of both barley and rice plants grown on the same Cu-deficient media is similar. Since barley plants showed deficient symptoms and rice plant did not, the minimal requirement of rice for Cu may be lower than barley plants(Dokiya, Owa, and Mitsui, 1968).

Yoshida(1975) summarized Cu deficiency symptoms of rice plants. He reported that the leaves of plants deficient in Cu appear bluish-green, and then become chlorotic near the tips. This chlorosis develops downward along both sides of the midrib, followed by dark brown necrosis of the tips. The new, emerging leaves fail to unroll and maintain a needle-like appearance along the entire length of the leaf or occasionally, along half the leaf, with the basal portion developing normally.

Tanaka and Yoshida(1970) listed critical levels of various nutrient elements for deficiencies or toxicities in the rice plants. Cu deficiency may occur when the rice straw contains less than 6 ppm and toxicity may occur when the Cu concentration exceeds 30 ppm at maturity. However, they emphasized that these levels should be used only as a guide for diagnosis, and would be subjected to modification according to criteria by which the disorders are defined, the status of other elements or substances in the soil, the stage of the growth of the plants, the cultivars, and environmental conditions.

Although the Cu requirement for rice is low, improved vegetative growth and yield has been noted following applications of Cu to the soil(Govindarajan and Rao, 1964; Mehrotra and Saxena, 1967; Sreedharan and George, 1969). Clark, Nearpass, and Sprecht(1957) reported that Cu application at the rate of 5-10 lb.acre for the control of diseases was beneficial to the growth and nutrition of rice plants.

Primavesi and Primavesi(1970) in Brazil reported that application of $CuSO_4$ at the rate of 3 kg/ha to paddy rice increased grain yields by 65-80% and prevented diseases. The benefits appeared to be associated with nutrient effect rather than fungicidal action of Cu.

Ishizuka, Tanaka, and Fujita(1961) found nearly normal development when rice was grown in the solution containing less than 1 ppm Cu, while severe toxicity symptoms were shown in the solution cultures containing more than 1 ppm of Cu. Hosoda(1942) noted that the growth of rice plants in pots was promoted by adding less than 25 ppm Cu to the soil, while severe toxicity occurred with 100 ppm Cu. Similar results were also reported by Rhyu(1977).

D. Chemical Methods Used for Assessing the Cu Status of Soils

There are several methods by which the concentration of Cu in the soil may be determined. The total content of soil Cu is not a good criteria for predicting response to applied Cu or the needs of the crop.

According to Follett and Lindsay(1970), a succesful chemical extractant for evaluating the availability of a nutrient for plants should remove only the portion of the element from the soil that either approximates or is proportional to that fraction of the element that plant roots can obtain from the soil. Fiskell(1965) also stated that chemical indexes of availability of soil Cu are measurements of one or more quantities of Cu extracted from the soil that are designed to reflect the relative capacities of different soils to supply Cu to plants. As a result, for many years there have been a number of attempts to use simple and meaningful means of extracting Cu from soils which in some way correspond to the amount of Cu removed by the plants grown on the soil.

In general, there are three basic methods used for extracting Cu from soil using aqueous solutions composed of various salts, dilute acids, and chelating agent. Several modifications have been introduced to the above-mentioned methods, such as variations in extracting time, concentration of extractant, ratio of soil to extractant, and pH of the extractant.

Cheng and Bray(1953) reported that 0.1N HCl extractable Cu ranged from 2.0 to 11.4 ppm in several soils in Illinois. Neelakantan and Mehta(1961) extracted soil Cu with neutral 1N NH_4OAc, 0.1N HCl, 0.5N HNO_3, 0.05M EDTA, 1N HCl, Morgan's solution, and 1N HNO_3. They found that the amount of Cu extracted by neutral 1N NH_4OAc gave the highest correlations with the uptake of Cu by sorghum plants. Lagunas Gil(1964) reported that NH_4OAc extracted too little Cu for detection by the colormetric methods used. Cu extracted by 1% Na_2EDTA at pH 9.0 was larger than that extracted by NH_4OAc, particularly in the organic soil horizon. However, each extractant recovered less Cu than did hot strong HNO_3+H_2SO_4. Sinha and Singh (1966) reported that 0.1N HCl extractable Cu was significantly related to the concentration of Cu in soybean plants.

Martens(1968) evaluated the extractable soil Cu using multiple correlation analyses with various soil chemical properties. He found that Cu uptake by maize was best predicted by the 1N HCl extractable Cu and the content of organic matter. He further reported that Cu bound by the soil organic matter fraction was the predominant source of HCl-soluble Cu.

According to Gupta and McLeod(1970), exchangeable (oxalate-extractable) Cu content of about 1.2 to 1.8 ppm in the soil was indicative of Cu deficiency for growing cereals under greenhouse conditions. Fiskell and Leonard(1967) reported that soil Cu extracted by water, 1N NH_4OAc at pH 4.8, or 1N HCl reflected treatment differences and rates of $CuSO_4$ or CuO. Linear regression relationships were established between root Cu and extractable soil Cu. Foliar Cu deficiency symptoms occurred when root-Cu was <3 ppm of the fresh weight, and when soil Cu extracted by 1N HCl was <2 ppm.

Dakhore, Naik, and Das(1963) found that foliar application of Cu at 0.5 and 1.0 lb/acre significantly increased grain yield of wheat grown on a sandy loam (pH 8.0) of medium fertility, containing 22.5 ppm total Cu and 2.55 ppm 0.02M EDTA extractable Cu.

In recent years, extensive research has been carried out on the behavior of various chelating agents. Chelation may be defined as the equilibrium reaction between a metal ion and a complexing agent, characterized by the formation of more than one bond between the metal and a molecule of the complexing agent and resulting in the formation of a ring structure incorporating the metal ion(Lehman, 1963). Since metals bound as chelates lose their cationic properties, they are much less subject to being fixed into an unavailable form by soil constituents. Plants may absorb metals either in the chelate form directly from the soil solution or in the cationic form after the metals separate from the chelating agent near the root surface.

Some of the more common chelating agents are EDTA (ethylenediamine tetraacetic acid), DTPA(diethylenetriamine pentaacetic acid), HEEDTA(hydroxyethyl ethylenediamine triacetic acid), and CDTA(cyclohexane trans 1,2-diamino tetraacetic acid)(Wallace, 1962).

Reith(1968) reported that the increase in grain yield produced by Cu applications was significantly correlated with soil Cu extracted by 0.05M EDTA. For extractable Cu values of <0.75, 0.75 - 1.10, and >1.10 ppm , cereal yield response to Cu applications were large, small, and none, respectively.

Dolar and Keeney(1971) suggested that EDTA plus 1$\underline{N}$ NH_4OAc and 0.1$\underline{N}$ HCl are two promising soil-tests for determining the availability of Cu, Zn, and Mn in a single extract.

A method using 0.005M DTPA with 0.01M $CaCl_2$ and 0.1M TEA, buffured to pH 7.3 developed by Lindsay and Norvell(1969) has been used widely for simultaneous determination of micronutrient cations. Karim, Sedberry, and Miller(1976) studied the distribution of micronutrient cations in the genetic horizons of 72 soils in Louisiana, and reported that DTPA-TEA extractable Cu ranged from 0.20 to 5.12 ppm in A_p horizons.

MATERIALS AND METHODS

Investigations were conducted in the greenhouse and in the laboratory to evaluate different chemical methods for extracting Cu from soils. Studies were also conducted to determined the influence of flooding periods on the extractable Cu, Zn, Mn, and Fe contents of soils. The effects of different rates of applied Cu and the influence of flooding, soil reaction(pH), and application of Cu on the production of dry matter, and the concentrations and uptake of Cu, Zn, Mn, Fe, P, Ca, and K by rice(*Oryza sativa L.* cultivar Saturn) plants were also investigated. An experiment was conducted in the field to determine the effects of Cu and Zn on the grain yield and chemical composition of rice plants grown on Crowley silt loam (Typic Albaqualf) at the Rice Experiment Station, Crowley, Louisiana.

Nineteen soils from the major rice growing areas in Louisiana were used in the greenhouse and laboratory investigations. Each sample of soils was alphabetically assigned a number from one to nineteen. The soils, subgroups, and locations are presented in Table 1.

A bulk sample of soil from each of the 19 locations was collected at random from the different fields to a depth of approximately 15 cm. The bulk sample of soil

Table 1. The soil types, subgroups, and locations of soil samples used in the greenhouse and laboratory investigations

Soil No.	Soil type	Subgroup	Location (Parish)
1.	Acadia sil1/	Aeric Ochraqualf	Acadia
2.	Alligator c2/	Vertic Haplaquept	Iberia
3.	Beauregard sil	Plinthaquic Paleudult	Beauregard
4.	Calloway sil	Glossaquic Fragiudalf	West Caroll
5.	Chastain c	Typic Fluvaquent	Union
6.	Crowley sil	Typic Albaqualf	Acadia
7.	Crowley sil	Typic Albaqualf	Acadia
8.	Falaya sil	Aeric Ochraqualf	East Baton Rouge
9.	Gallion vfsl3/	Typic Hapludalf	Grant
10.	Grenada sil	Glossic Fragiudalf	Franklin
11.	Harris c	Typic Haplaquoll	Vermilion
12.	Lafitte muck	Typic Medisaprist	Jefferson
13.	Mhoon sil	Typic Fluvaquent	Plaquemines
14.	Moreland c	Vertic Hapludalf	Rapides
15.	Myatt fsl4/	Typic Ochraquult	Tangipahoa
16.	Olivier sil	Aquic Fragiudalf	East Baton Rouge
17.	Severn vfsl	Typic Udifluvent	Bossier
18.	Severn vfsl	Typic Udifluvent	Bossier
19.	Stough fsl	Fragiaquic Paleudult	Tangipahoa

1/ sil : silt loam 2/ c : clay 3/ vfsl : very fine sandy loam

4/ fsl : fine sandy loam.

was air-dried, crushed, sieved through a 0.5 cm plastic screen, and stored in a plastic lined container. The soil was mixed and a 3-kg sub-sample was sieved again through a 20-mesh stainless steel screen, and stored in plastic bags for chemical analysis.

Prior to the conduction of the greenhouse and field experiments, the extractable P, K, Ca, and Mg contents of each of the soils were determined. The soil reaction (pH) and organic matter contents of the soils were also determined. The chemical methods used to determine the fertility level and lime status of the soils were described by Brupbacher, Bonner, and Sedberry(1968).

Soil reaction(pH) was measured at a soil-to-water ratio of approximately 1:1 by volume. The organic matter content of the soil samples was determined by the chromic acid method proposed by Walkey and Black(1934).

Phosphorus was extracted from the soils with 0.1<u>N</u> HCl, containing 0.03<u>N</u> NH_4F, at a soil-to-solution ratio of 1:20 for 15 minutes. The concentration of P in the soil extract was determined using an Auto Analyzer.

Potassium, calcium, and magnesium were extracted with 1N NH_4OAc, pH 7.0, at a soil-to-solution ratio of 1:20 for 15 minutes, and determined using a Perkin-Elmer Model 5,000 atomic absorption spectrophotometer.

In all of the pot experiments conducted in the greenhouse, a 600 g sample of soil on an oven dry basis was placed into a 1-liter cardboard container lined with a polyethylene bag.

Each soil in the containers in all experiments received a uniform preplant application of 60 ppm of N, 40 ppm of P, and 40 ppm of K. The sources of N, P, and K were urea, 46% N, concentrated superphosphate(CSP), 20.2% P, and muriate of potash, 49.8% K. In addition, 20 ppm of N was topdressed at 25 days after seeding rice.

Saturn rice seeds were pre-soaked in distilled water for 30 hours. Fifteen uniformly sprouted seedlings were planted in each container. The moisture content of soil was adjusted to approximately 80% of field capacity with distilled water for the first 10 days.

The rice seedlings were thinned to eight plants per container 10 days after planting, and flooded to a depth of approximately 3 cm with distilled water. One week later, the depth of the water was increased to approximately 6 cm, and the water was maintained at this level throughout the growing period.

The moisture content of the soil in the containers comprising the nonflooded treatment was maintained at approximately 80% of field capacity by addition of distilled water 3 times daily throughout the growing period.

The rice plants in all of the greenhouse experiments were harvested 6 weeks after seeding. The tops of the plants were cut immediately above ground level, washed by dipping into distilled water, placed in cloth bags, and dried in a forced-draft oven for 30 hours at 80°C. The dry weight of plants from each container was recorded.

The plants were then ground to pass through a 20-mesh screen in a stainless steel Wiley mill. The ground plant tissue was throughly mixed, and stored in a 125 ml screw-top glass container for chemical analysis.

The plant tissue was dried immediately before chemical analysis in an oven for 3 hours to remove any moisture that may have accumulated during storage.

Samples of plant tissue were digested according to the procedure outlined by Toth, et al.(1948). A two-gram plant tissue sample was weighed into a 200 ml tall beaker. Twenty ml of a 3:1 mixture of concentrated HNO_3 and $HClO_4$ were added and allowed to stand overnight. The partially digested, straw-colored sample was heated on a hot plate until 3 to 5 ml of the clear mixture remained. The acid solution diluted with distilled water was filtered through Whatman No. 42 filter paper. The filtrate was collected in a 100 ml volumetric flask, and made up to volume with distilled water. This digest was stored in a screw-cap plastic bottle. The concentration of Cu, Zn, Mn, Fe, Ca, and K in the plant tissue was determined on a Perkin-Elmer Model 503 atomic absorption spectrophotometer. P was determined by the vanado-molybdate method on a Bausch and Lomb Model 20 spectrophotometer as described by Yoshida, et al.(1972).

The objective of the initial greenhouse and laboratory experiment was to evaluate eight chemical extractants for determining the contents of Cu in the 19 soils listed in Table 1. The concentration and uptake of Cu by rice plants grown under flooded conditions were determined for the evaluation of the chemical extractants. Three replicates of each of the 19 soils were arranged in a completely randomized design.

Three 100 g sub-samples of the 19 soils were transferred into 200 ml tall beakers and flooded to approximately 2 cm depth with distilled water and incubated at 28°C for 6 weeks in a incubator. Soil reaction(pH) was determined on the flooded soils at the end of the 6-week incubation period. The soils were placed into a forced-draft oven and the water was evaporated rapidly with no heat. When the moisture content of the samples reached approximately 80% of field capacity, samples were weighed for chemical analysis. Three 10 g soil-samples were also taken, allowed to air-dry, and weighed to calculate the moisture content.

The contents of the air-dried and flooded soil samples were determined with the following extracting solutions: (1) 0.5N HCl+0.05N $AlCl_3$(Mehlich and Bowling, 1975), (2) 0.5N HNO_3(Neelakantan and Mehta, 1961), (3) 0.5N HCl(Grewal, et al., 1969), (4) 0.1N HCl(Wear and Sommer,1948), (5) 0.01M ethylenediamine tetraacetic acid(EDTA) with 1N $(NH_4)_2CO_3$(Trierweiler and Lindsay, 1969), (6) 0.01M EDTA with 1N NH_4OAc(Dolar, et al.,1971), (7) 0.005M diethylenetriamine pentaacetic acid(DTPA) with 0.1M $CaCl_2$ and 0.1M triethanolamine(TEA), buffured at pH 7.3(Lindsay and Norvell, 1969), and (8) 1N NH_4OAc at pH 4.8(Lyman and Dean, 1942). The extracting time and soil-to-solution ratio are presented in Table 2.

The soil-extracting solution mixture was shaken in 125 ml Erlenmeyer flasks on an Eberbach reciprocating shaker at 180 oscilations per minute. The solution was filtered through a Whatman No. 2V filter paper into a screw-cap plastic bottle. The Cu concentration was determined in the filtrate by atomic absorption spectrophotometry. The Cu concentrations of the soil extracts from the flooded samples were adjusted to account for the dilution effect of soil moisture.

The second experiment was conducted to determine the influence of five flooding periods on 0.1N HCl and

Table 2. The extracting solutions, extracting times, soil:solution ratios, and references used for determining the Cu contents in the soils.

Extracting solution	Extracting time	Soil:solution ratio	Reference
	minutes		
1. $0.5\underline{N}$ HCl+$0.05\underline{N}$ $AlCl_3$	5	1 : 5	Mehlich and Bowling(1975)
2. $0.5\underline{N}$ HNO_3	15	1 : 5	Neelakantan and Mehta(1961)
3. $0.5\underline{N}$ HCl	15	1 : 5	Grewal, et al.(1968)
4. $0.1\underline{N}$ HCl	15	1 : 10	Wear and Sommer(1948)
5. 0.01M EDTA+$1\underline{N}$ $(NH_4)_2CO_3$	30	1 : 2	Trierweiler and Lindsay(1969)
6. 0.01M EDTA+$1\underline{N}$ NH_4OAc	60	1 : 10	Dolar and Keeney(1971)
7. 0.005M DTPA-TEA, pH 7.3	120	1 : 2	Lindsay and Norvell(1969)
8. $1\underline{N}$ NH_4OAc, pH 4.8	60	1 : 2	Lyman and Dean(1942)

DTPA-TEA extractable Cu, and on the DTPA-TEA extractable Zn, Mn, and Fe contents of 5 soils. The soils used in this experiment were Alligator clay(soil No. 2), Beauregard silt loam(soil No. 3), Chastain clay(soil No. 5), Crowley silt loam(soil No. 6), and Falaya silt loam (soil No. 8).

Three 100-g samples of the five soils from each of the flooding periods were placed into 200 ml tall beakers and flooded with distilled water to approximately 2 cm depth. The soil samples were incubated at 28 °C for 0, 1, 2, 4, and 6 weeks. Each of the flooded treatments was begun in order that all of the samples were extracted at the same time. Samples which represented a 0 week frooding treatment were flooded immediately before being placed in a forced-draft oven with no heat to remove excess water.

The third experiment was conducted in the greenhouse to determine the influence of four rates of Cu on the production of dry matter, on the concentration and uptake of Cu, and on the concentration of Zn, Mn, and Fe in Saturn rice plants grown on Myatt fine sandy loam (soil No. 15) and Lafitte muck(soil No. 12).

The rates of Cu were: 0, 5, 10, and 20 ppm. Each of the four rates of Cu was arranged in a randomized block design with 3 replications. The source of Cu was reagent-grade $CuSO_4 \cdot 5H_2O$, 25% Cu. An aqueous solution of $CuSO_4 \cdot 5H_2O$ was added to the soil in each container before seeding and throughly incorporated by mixing.

Soil samples were collected from each container immediately after harvesting, and the Cu content was determined by extracting with 0.5N HCl+0.05N $AlCl_3$, 0.5N HCl, 0.1N HCl, DTPA-TEA, pH 7.3, and 1N NH_4OAc, pH 4.8.

The fourth experiment was conducted to determine the influence of flooding, soil reaction(pH), and application of Cu on the production of dry matter, and the concentration and uptake of Cu, Zn, Mn, Fe, P, Ca, and K by Saturn rice plants grown on Lafitte muck(soil No. 12).

A split-split plot design with four replications was employed. Two water regimes, flooded and nonflooded, were assigned to the main-plots; six rates of soil reaction, pH 4.2, 4.8, 5.4, 5.9, 6.3, and 6.7, were assigned to the sub-plots; and two rates of Cu, no Cu and 5 ppm Cu, were assigned to the sub-sub-plots.

Soil reaction(pH) was adjusted by applying reagent--grade $CaCO_3$, at the rates of 0, 0.5, 1.0, 1.5, 2.0, and 2.5% of soil by weight. The $CaCO_3$ was throughly mixed into soil two weeks before seeding. The moisture content of soil was maintained at approximately 80% of field capacity.

Cu was applied to the Lafitte muck at a rate equivalent to 5 ppm of Cu as $CuSO_4 \cdot 5H_2O$, 25% Cu in an aqueous solution. The Cu was throughly incorporated into the soil.

The seventh leaf("Y" leaf) was sampled for chlorophyll analysis. The sampled leaves were weighed for fresh weight, cut approximately 5 mm in length and a 0.2 g sample was placed into a test tube containing 20 ml of the 80% ethanol. The test tube was covered with parafilm, and the chlorophyll was extracted in a water bath at 80 °C for 30 minutes, and cooled at room temperature. The chlorophyll content in the extract was measured spectrophotometrically. The total chlorophyll content was calculated according to the equation described by Yoshida, et al.(1972), and multiplied by fresh weight.

A field experiment was conducted for two years on Crowley silt loam at the Rice Experiment Station, Crowley, Louisiana, to determine the effects of applications of Cu and Zn, individually and in combination, on rice grain yields, and on the concentration of Cu, Zn, Mn, and Fe in the leaves of Saturn rice plants.

Prior to the initiation of the field experiment the Crowley soil had been water-leveled to facilitate flooding and drainage. Soil samples were collected from each of 16 plots prior to the application of fertilizer materials first year. The soil pH was 7.5. The extractable P, Ca, K, and Mg contents were 5, 1,750, 78, and 397 ppm, respectively. The organic matter content was 1.0%. The DTPA-TEA extractable Cu and Zn contents were 1.00 and 1.32 ppm, respectively.

The experimental arrangement was a randomized block design with four replications of each of the four treatment combinations.

Copper as Cu-chelate, 13% Cu, and zinc as Zn-chelate, 14.2% Zn, were applied at rates equivalent to 0.44 kg/ha of Cu and 1.75 kg/ha of Zn.

Cu and Zn, alone and in combination, were broadcasted each year to the surface of the soil in an aqueous solution with a gravity flow applicator immediately after planting.

Each plot received a uniform application of 112 kg N, 67 kg P, and 67 kg of K per ha with a drill at planting. An additional application of 45 kg of N was made when the rice plants reached the first joint stage of development. The sources of N, P, and K were urea, 46% N, concentrated superphosphate(CSP), 20.2% P, and muriate of potash, 49.8% K, respectively.

Saturn rice was planted with a drill at a seeding rate of 112 kg/ha. Each plot contained 12 rows spaced 17.8 cm apart. The individual plot size was 2.1 by 15.2 m.

Leaf samples were collected each year from rice plants growing on individual plots. The most fully matured leaf was sampled annually at the first joint stage of development for chemical analyses. Fifty leaves were collected from rice plants growing on each plot. The leaves were placed in cotton bags, dried in a forced-draft oven at 80 °C, and ground in a stainless steel Wiley mill to pass a 20-mesh sieve. The plant material was stored in 125 ml screw-cap glass containers for chemical analyses.

All of the yield and the plant tissue and soil composition data in all of the experiments were statistically analyzed by the analysis of variance technique to test for significant differences between treatment means and interaction effects. Simple and multiple correlation coefficients and regression equations were calculated among certain variables.

RESULTS AND DISCUSSION

Certain chemical properties of the soils used in the greenhouse and laboratory investigations are presented in Table 3. The textural classification of the mineral soils varied from fine sandy loams to clays. One muck soil was included in the investigations.

The P content of the soils varied from 15 ppm in Olivier silt loam(soil No. 16) to 310 ppm in Mhoon silt loam(soil No. 13). The Ca content varied from 338 ppm in Gallion very fine sandy loam(soil No. 9) to 5,680 ppm in Alligator clay(soil No. 2). The Mg content varied from 55 ppm in Stough fine sandy loam(soil No. 19) to 1,450 ppm in Moreland clay(soil No. 14). The K content varied from 15 ppm in Stough fine sandy loam(soil No. 19) to 596 ppm in Alligator clay(soil No. 2).

The organic matter content of 17 of the 19 soils varied from 0.53% in Severn very fine sandy loam(soil No. 18) to 4.38% in Myatt fine sandy loam(soil No. 15) with a mean of 1.49%. The organic matter contents of Harris clay(soil No. 11) and Lafitte muck(soil No. 12) were 15.33 and 26.45%, respectively. The soil reaction varied from pH 4.1 in Gallion very fine sandy loam(soil No. 9) to pH 7.4 in Crowley silt loam(soil No. 6) and Severn very fine sandy loam(soil No. 18).

Table 3. Certain chemical properties of the soils used in the greenhouse and laboratory investigations.

Soil No.	Soil type	Extractable				Organic matter[3/]	Soil reaction[4/]
		P[1/]	Ca[2/]	Mg[2/]	K[2/]		
		- - - - - -	ppm	- - - - - -		%	pH
1.	Acadia sil[5/]	36	892	68	41	0.58	7.0
2.	Alligator c[6/]	145	5,680	1,314	596	3.85	5.7
3.	Beauregard sil	172	879	72	88	1.35	5.7
4.	Calloway sil	44	1,150	497	90	1.40	4.6
5.	Chastain c	38	1,327	563	181	3.46	4.2
6.	Crowley sil	28	2,089	463	84	0.58	7.4
7.	Crowley sil	55	1,264	298	52	0.96	6.4
8.	Falaya sil	73	689	162	82	1.15	5.5
9.	Gallion vfsl[7/]	193	338	97	109	0.67	4.1
10.	Grenada sil	96	623	203	102	0.67	5.7
11.	Harris c	26	1,456	1,132	172	15.33	4.3
12.	Lafitte muck	40	2,121	923	226	26.45	4.2

Table 3. Continued

Soil No.	Soil type	Extractable P[1]	Ca[2]	Mg[2]	K[2]	Organic matter[3]	Soil reaction[4]
		- - - - ppm			- - - -	%	pH
13.	Mhoon sil	310	1,572	471	138	0.63	7.0
14.	Moreland c	154	4,764	1,452	379	2.12	6.5
15.	Myatt fsl[8]	46	1,744	429	122	4.38	5.5
16.	Olivier sil	15	487	122	70	0.77	4.9
17.	Severn vfsl	104	719	300	160	0.96	6.0
18.	Severn vfsl	231	1,298	266	92	0.53	7.4
19.	Stough fsl	27	344	55	15	1.35	4.5

1/ P was extracted with 0.1N HCl containing 0.03N NH_4F at a soil-to-solution ratio of 1:20 for 15 minutes.

2/ Ca, Mg, and K were extracted with 1N NH_4OAc, pH 7.0 at a soil-to-solution ratio of 1:10 for 15 minutes.

3/ Organic matter was determined by Walkey-Black method.

4/ Soil reaction(pH) was measured at a soil-to-water ratio of approximately 1:1 by volume.

5/ sil : silt loam. 6/ c : clay. 7/ vfsl : very fine sandy loam.

8/ fsl : fine sandy loam.

The influence of flooding on the soil reaction(pH) of the 19 soils is presented in Table 4. Flooding the soils with distilled water and incubation for six weeks at 28 °C resulted in an increase in the soil reaction of all of the soils. Relatively larger increases in the pH values of the flooded soils were noted on Falaya silt loam(soil No 8), Grenada silt loam(soil No. 10), and Severn very fine sandy loam(soil No. 17). Relatively small increases in soil reaction resulting from flooding were observed on Calloway silt loam(soil No. 4), Chastain clay(soil No. 5), Gallion very fine sandy loam(soil No. 9), Harris clay(soil No. 11), Lafitte muck(soil No. 12), and Stough fine sandy loam(soil No. 19), even though these soils had low initial pH values. Changes in redox potential and pH brought about by flooding are well documented(Ponnamperuma, 1955; Gotoh and Patrick, 1972, 1974; Ponnamperuma, 1972). Redman and Patrick(1965) reported that submergence tended to shift the soil pH to value near neutral, with acid soils increasing in pH and alkaline soils decreasing in pH. Bostrom(1967) reported that increased pH of acid soil upon submergence depended on the release of OH^- and consumption of H^+, and on the ratio of H^+ to electron consumed.

Patrick(1964) explained an increase in pH accompanying a decrease in redox potential(Eh) on the basis that

Table 4. The effect of flooding on the soil reaction(pH) of 19 soils.

Soil No.	Soil type	Soil reaction	
		Air-dried	Flooded[1/]
		- - - - pH - - - -	
1.	Acadia sil	7.0	7.6
2.	Alligator c	5.7	6.3
3.	Beauregard sil	5.7	5.8
4.	Calloway sil	4.6	4.9
5.	Chastain c	4.2	4.4
6.	Crowley sil	7.4	7.5
7.	Crowley sil	6.4	6.8
8.	Falaya sil	5.5	7.0
9.	Gallion vfsl	4.1	4.2
10.	Grenada sil	5.7	6.9
11.	Harris c	4.3	4.4
12.	Lafitte muck	4.2	4.3
13.	Mhoon sil	7.0	7.1
14.	Moreland c	6.5	6.8
15.	Myatt fsl	5.5	6.4
16.	Olivier sil	4.9	5.3
17.	Severn vfsl	6.0	6.9
18.	Severn vfsl	7.4	7.5
19.	Stough fsl	4.5	4.9

1/ Soil was flooded with distilled water and incubated for 6 weeks at 28 °C.

at low Eh, ferric hydroxide is reduced to ferrous hydroxide as follow:

$$Fe(OH)_3 + e^- \rightleftharpoons Fe(OH)_2 + OH^-$$

However, the pH of an acid soil low in reducible Fe and high in organic matter content, may not change appreciably even after several weeks of submergence(Ponnamperuma, 1972).

The Cu contents extracted from air-dried and flooded soils with eight extracting solutions are presented in Tables 5 and 6, and Figure 1. In general, the dilute acids removed consistently larger amounts of Cu than did the chelating agents and NH_4OAc on both air-dried and flooded soils. The 0.5$\underline{N}$ HCl+0.05$\underline{N}$ $AlCl_3$ extractant removed relatively larger amounts of Cu from all of the soils than did the other extractants evaluated.

The data show that 1$\underline{N}$ NH_4OAc adjusted to pH 4.8 extracted significantly smaller quantities of Cu from the air-dried and flooded soils than did the other extractants. The results agree with those reported by Bandyopadhya and Adhikari(1968).

The EDTA+$(NH_4)_2CO_3$ and EDTA+NH_4OAc extractants removed larger amounts of Cu than did the DTPA-TEA. The DTPA-TEA extractable Cu ranged from 0.22 to 3.62 ppm in the air-dried soils and from 0.19 to 2.76 ppm in the flooded soils. These ranges in extractable Cu are similar to the results obtained by Follett and Lindsay(1970), and

Table 5. The Cu contents extracted from 19 air-dried soils with eight extracting solutions.

Soil No.	Soil type	HCl+ $AlCl_3$	0.5N HNO_3	0.5N HCl	0.1N HCl	EDTA+ $(NH_4)_2CO_3$	EDTA+ NH_4OAc	DTPA-TEA pH 7.3	NH_4OAc pH 4.8
		- - - - - - - ppm, mean of 3 replications - - - - - - - -							
1.	Acadia sil	1.35	1.35	1.25	1.30	1.07	1.30	0.49	0.23
2.	Alligator c	3.61	4.12	3.80	2.13	2.22	3.60	3.19	0.27
3.	Beauregard sil	1.20	0.95	0.85	1.30	0.75	1.07	0.40	0.13
4.	Calloway sil	1.97	1.62	1.69	1.67	1.39	1.70	1.24	0.29
5.	Chastain c	2.34	2.07	2.22	1.87	1.47	2.20	0.30	0.17
6.	Crowley sil	2.57	2.17	2.03	2.17	1.38	2.00	0.85	0.19
7.	Crowley sil	2.59	2.33	2.42	2.40	1.90	2.40	0.92	0.21
8.	Falaya sil	2.98	2.43	2.41	2.47	2.11	2.20	1.40	0.28
9.	Gallion vfsl	1.14	1.00	1.00	0.93	1.03	1.07	0.70	0.23
10.	Grenada sil	1.98	1.52	1.65	1.60	1.52	1.42	0.99	0.20
11.	Harris c	2.24	2.38	2.21	1.57	1.27	2.17	0.35	0.22
12.	Lafitte muck	2.25	2.41	2.21	1.47	1.81	2.13	0.22	0.25

Table 5. Continued

Soil No.	Soil type	HCl+ $AlCl_3$	0.5N HNO_3	0.5N HCl	0.1N HCl	EDTA+ $(NH_4)_2CO_3$	EDTA+ NH_4OAc	DTPA-TEA pH 7.3	NH_4OAc pH 4.8
		- - - - - - - - - ppm, mean of 3 replications - - - - - - - - -							
13.	Mhoon sil	3.54	3.50	3.58	3.70	2.07	3.27	2.39	0.27
14.	Moreland c	7.34	7.45	7.45	5.50	5.22	5.73	3.62	0.43
15.	Myatt fsl	0.84	0.81	0.60	0.63	0.39	0.63	0.28	0.20
16.	Olivier sil	1.81	1.60	1.61	1.67	2.00	1.83	1.12	0.27
17.	Severn vfsl	1.73	1.50	1.32	1.40	1.40	1.52	1.09	0.25
18.	Severn vfsl	2.60	2.30	2.22	2.33	1.70	2.40	0.92	0.23
19.	Stough fsl	1.85	1.92	1.72	1.87	1.87	1.53	0.75	0.27
	Mean	2.42	2.29	2.22	2.00	1.71	2.11	1.12	0.25
	Range	0.84-7.34	0.81-7.45	0.60-7.45	0.63-5.50	0.39-5.22	0.63-5.73	0.22-3.62	0.17-0.43

Table 6. The Cu contents extracted from 19 flooded soils with eight extracting solutions.

Soil No.	Soil type	HCl+ $AlCl_3$	0.5N HNO_3	0.5N HCl	0.1N HCl	EDTA+ $(NH_4)_2CO_3$	EDTA+ NH_4OAc	DTPA-TEA pH 7.3	NH_4OAc pH 4.8
		- - - - - - - ppm, mean of 3 replications - - - - - - - -							
1.	Acadia sil	1.49	1.27	1.33	1.20	1.11	1.33	0.53	0.22
2.	Alligator c	5.03	4.90	5.41	3.83	4.07	5.13	1.96	0.31
3.	Beauregard sil	1.14	0.85	0.84	1.20	0.73	1.00	0.35	0.15
4.	Calloway sil	1.65	1.65	1.66	1.60	1.19	1.63	0.81	0.27
5.	Chastain c	2.75	1.93	2.23	1.67	1.20	1.87	0.23	0.17
6.	Crowley sil	2.29	2.17	1.66	2.00	1.35	1.77	0.69	0.20
7.	Crowley sil	2.43	2.30	2.51	2.53	1.71	2.40	0.85	0.21
8.	Falaya sil	3.77	3.28	3.49	3.83	2.96	3.00	1.05	0.35
9.	Gallion vfsl	1.07	1.02	0.89	0.97	1.00	1.10	0.57	0.22
10.	Grenada sil	2.85	2.67	2.87	2.63	2.42	2.83	0.84	0.33
11.	Harris c	2.58	2.15	2.33	1.37	1.27	2.13	0.25	0.20
12.	Lafitte muck	2.72	2.35	2.18	1.43	1.44	2.27	0.19	0.23

Table 6. Continued.

Soil No.	Soil type	HCl+ $AlCl_3$	0.5N HNO_3	0.5N HCl	0.1N HCl	EDTA+ $(NH_4)_2CO_3$	EDTA+ NH_4OAc	DTPA-TEA pH 7.3	NH_4OAc pH 4.8
		- - - - - - -	-	-	ppm, mean of 3 replications	-	-	- - - - - - - -	
13.	Mhoon sil	3.56	3.42	3.50	3.53	2.06	3.07	1.63	0.27
14.	Moreland c	7.80	7.75	8.09	6.93	6.34	6.07	2.76	0.52
15.	Myatt fsl	1.09	0.77	0.67	0.60	0.48	0.87	0.42	0.22
16.	Olivier sil	1.73	1.60	1.65	1.53	1.62	1.60	0.86	0.29
17.	Severn vfsl	2.32	2.32	1.84	2.23	2.01	2.20	1.00	0.32
18.	Severn vfsl	2.42	2.23	2.30	2.23	1.74	2.33	0.79	0.24
19.	Stough fsl	2.00	1.92	1.88	1.67	1.87	1.50	0.79	0.25
	Mean	2.67	2.45	2.49	2.26	1.93	2.32	0.87	0.26
	Range	1.07-7.80	0.77-7.75	0.67-8.09	0.60-6.93	0.48-6.34	0.87-6.07	0.19-2.76	0.17-0.52

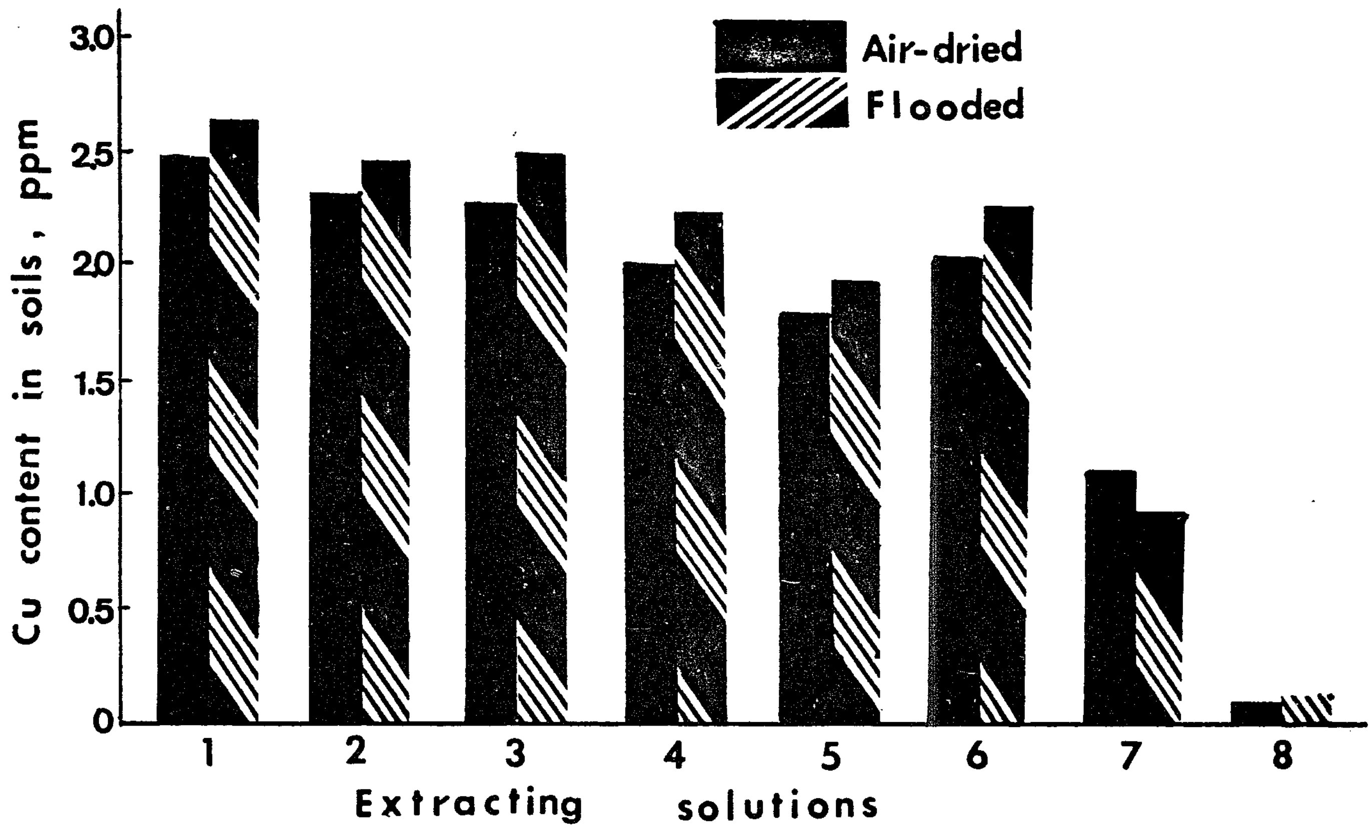

Figure 1. The Cu contents extracted with eight extracting solutions from air-dried and flooded soils.

1) 0.5N $HCl+0.05N\ AlCl_3$ 2) 0.5N HNO_3 3) 0.5N HCl
4) 0.1N HCl 5) 0.01M EDTA+1N $(NH_4)_2CO_3$
6) 0.01M EDTA+1N NH_4OAc 7) 0.005M DTPA-TEA, pH 7.3
8) 1N NH_4OAc, pH 4.8

Karim, Sedberry, and Miller(1976). The data show that relatively smaller quantities of soil-Cu were chelated with the DTPA-TEA extractant than with the EDTA extractants.

According to Lindsay and Norvell(1978), 0.2 ppm of DTPA-TEA extractable Cu was tentatively proposed as a critical level of Cu in soils. The data in Table 6 show that DTPA-TEA extractable Cu on flooded Lafitte muck was below the critical level. Relatively low levels of DTPA-TEA extractable Cu were found on Chastain clay(soil No.5), Harris clay(soil No. 11), and Myatt fine sandy loam (soil No. 15).

The data also show that the four dilute acids and two EDTA extractants tended to remove larger quantities of Cu from flooded soils than they did from air-dried soils. However, the differences in the Cu contents extracted from air-dried and flooded soils with the dilute acids and EDTA extractants were not statistically significant on 14 of the 19 soils.

Flooding the soils resulted in a significant increase in the dilute acids and EDTA extractable Cu on Alligator clay(soil No.2), Falaya silt loam(soil No.8), Grenada silt loam(soil No.10), Moreland clay(soil No.14), and Severn very fine sandy loam(soil No.17). The DTPA-TEA extractant tended to remove lower amounts of Cu from flooded soils than it did from air-dried soils.

The order of the removal of Cu from air-dried soils with the eight extractants was: 0.5N HCl+0.05N $AlCl_3$ > 0.5N HNO_3 > 0.5N HCl > EDTA+NH_4OAc > 0.1N HCl > EDTA+$(NH_4)_2CO_3$ ≫ DTPA-TEA, pH 7.3 ⋙ 1N NH_4OAc, pH 4.8. The order of the removal of Cu from flooded soils was: 0.5N HCl+0.05N$AlCl_3$ > 0.5N HCl > 0.5N HNO_3 > 0.1N HCl > EDTA+NH_4OAc > EDTA+$(NH_4)_2CO_3$ ≫ DTPA-TEA, pH 7.3 ⋙ 1N NH_4OAc, pH 4.8.

Relationships as shown by simple correlation coefficients(r) between Cu contents extracted from air-dried and flooded soils with eight extracting solutions and certain chemical properties of the soils are presented in Tables 7 and 8.

Harris clay(soil No. 11) and Lafitte muck(soil No. 12) were not included in the statistical analyses relating Cu to organic matter content of soils, because these two soils contained significantly higher amounts of organic matter than did the mineral soils.

The data in Tables 7 and 8 show that nonsignificant relationships were found between P and Cu removed with all of the reagents used for extracting Cu from air-dried and flooded soils with one exception. There was a significant relationship between P and DTPA-TEA extractable Cu on the air-dried soils. Significant correlation coeffi-

Table 7. Relationships as shown by simple correlation coefficients(r) between Cu contents extracted from 19 air-dried soils with eight extracting solutions and certain chemical properties of the soils.

Cu contents of soils extracted with	P	K	Ca	Mg	O.M.1/	pH	
						Air-dried	Flooded
	r values						
1. 0.5N HCl+0.05N $AlCl_3$	0.304	0.585**	0.714**	0.688**	0.106	0.316	0.262
2. 0.5N HNO_3	0.298	0.668**	0.783**	0.759**	0.180	0.268	0.203
3. 0.5N HCl	0.310	0.632**	0.748**	0.730**	0.152	0.268	0.203
4. 0.1N HCl	0.403	0.367	0.533*	0.491*	-0.066	0.428	0.351
5. EDTA+$(NH_4)_2CO_3$	0.202	0.492*	0.593**	0.572*	0.014	0.198	0.173
6. EDTA+NH_4OAc	0.339	0.661**	0.764**	0.740**	0.138	0.292	0.208
7. DTPA-TEA, pH 7.3	0.468*	0.689**	0.738**	0.557*	0.156	0.347	0.348
8. 1N NH_4OAc, pH 4.8	0.240	0.404	0.486*	0.473*	0.064	0.104	0.120

* : $P < .05$ ** : $P < .01$

1/ Organic matter contents of Harris clay(soil No. 11) and Lafitte muck(soil No. 12) were not included in correlation analyses.

Table 8. Relationships as shown by simple correlation coefficients(r) between Cu contents extracted from 19 flooded soils with eight extracting solutions and certain chemical properties of the soils.

Cu contents of soils extracted with	P	K	Ca	Mg	O.M[1/]	pH Air-dried	pH Flooded
	------------- r values -------------						
1. 0.5N HCl+0.05N $AlCl_3$	0.266	0.712**	0.771**	0.736**	0.226	0.237	0.248
2. 0.5N HNO_3	0.295	0.704**	0.772**	0.717**	0.173	0.275	0.280
3. 0.5N HCl	0.293	0.716**	0.774**	0.718**	0.213	0.240	0.252
4. 0.1N HCl	0.369	0.556*	0.643**	0.542*	0.058	0.379	0.410
5. EDTA+$(NH_4)_2CO_3$	0.255	0.666**	0.710**	0.607**	0.147	0.244	0.295
6. EDTA+NH_4OAc	0.324	0.781**	0.810**	0.730**	0.214	0.268	0.290
7. DTPA-TEA, pH 7.3	0.449	0.604**	0.681**	0.494*	0.098	0.404	0.416
8. 1N NH_4OAc, pH 4.8	0.182	0.440	0.458*	0.408	0.014	0.188	0.312

* : $P < .05$ ** : $P < .01$

1/ Organic matter contents of Harris clay(soil No. 11) and Lafitte muck(soil No. 12) were not included in correlation analyses.

cients(r) were found between the K, Ca, and Mg contents of soils and extractable Cu with eight extracting methods for both air-dried and flooded soils with only four exceptions.

The pH of the air-dried and flooded soils, and organic matter content were not significantly correlated with soil-Cu. No significant relationships between extractable Cu and soil pH in Ap horizons of the 72 soils in Louisiana were reported by Karim, Sedberry, and Miller(1976).

The production of dry matter, and the concentration and uptake of Cu by Saturn rice plants grown for six weeks under flooded conditions in the greenhouse are presented in Table 9. The production of dry matter varied from 2.7 g on Severn very fine sandy loam(soil No.18) to 9.7 g on Alligator clay(soil No.2). Significantly higher amounts of dry matter were produced by plants grown on Alligator clay(soil No.2), Beauregard silt loam(soil No. 3), and Severn very fine sandy loam(soil No.17). Significantly lower amounts of dry matter were produced by plants on Acadia silt loam(soil No.1), Crowley silt loam (soil No.6), and Severn very fine sandy loam(soil No.18).

The concentrations of Cu in rice tissue were significantly lower on Chastain clay(soil No. 5), Harris clay(soil No.11), Lafitte muck(soil No. 12), and

Table 9. The production of dry matter, and the concentration and uptake of Cu by Saturn rice plants grown for six weeks under flooded conditions in the greenhouse.

Soil No.	Soil type	Dry matter	Cu concentration	Cu uptake
		g/pot	ppm	µg/pot
1.	Acadia sil	3.4	9.00	30.6
2.	Alligator c	9.7	8.10	78.6
3.	Beauregard sil	8.2	6.97	57.2
4.	Calloway sil	5.3	11.70	62.0
5.	Chastain c	6.6	5.95	39.3
6.	Crowley sil	3.3	9.25	30.7
7.	Crowley sil	7.2	8.00	57.6
8.	Falaya sil	6.8	8.90	60.5
9.	Gallion vfsl	6.1	9.90	60.4
10.	Grenada sil	6.5	9.65	62.7
11.	Harris c	5.2	6.53	34.0
12.	Lafitte muck	6.6	5.85	38.6
13.	Mhoon sil	4.4	13.40	59.0
14.	Moreland c	7.5	11.90	89.3
15.	Myatt fsl	6.7	5.97	40.0
16.	Olivier sil	5.6	8.67	48.6
17.	Severn vfsl	8.2	9.70	79.5
18.	Severn vfsl	2.7	12.00	31.4
19.	Stough fsl	7.9	9.75	77.0
	LSD, 5%	1.5	1.29	14.7

Myatt fine sandy loam(soil No.15). Relatively high concentrations of Cu in the tissue were found in the plants grown on Calloway silt loam(soil No.4), Mhoon silt loam (soil No.13), Moreland clay(soil No.14), and Severn very fine sandy loam(soil No.18).

The uptake of Cu by rice was relatively low on Acadia silt loam(soil No.1), Crowley silt loam(soil No.6), Harris clay(soil No. 11), and Severn very fine sandy loam(soil No.18).Relatively high uptake of Cu was found by the plants on Alligator clay(soil No.2), Moreland clay(soil No.14), Severn very fine sandy loam(soil No.17), and Stough fine sandy loam(soil No.19).

Simple correlation analyses between the production of dry matter, the concentration and uptake of Cu by rice plants and soil-Cu extracted with eight extracting solutions were used to determine the suitability of chemical methods for evaluating the Cu status of soils. Relationships as shown by simple correlation coefficients between Cu contents extracted from air-dried and flooded soils with eight extracting solutions and dry matter production, concentration and uptake of Cu by rice are presented in Tables 10 and 11.

No significant relationships were found between the production of dry matter by rice plants and Cu extracted from air-dried and flooded soils with eight extracting

Table 10. Relationships as shown by simple correlation coefficients(r) between Cu contents extracted from 19 air-dried soils with eight extracting solutions and dry matter production, Cu concentration, and Cu uptake by Saturn rice plants.

Cu contents of soils extracted with		Dry matter production	Cu concentration	Cu uptake
		------ r values -------		
1.	0.5N HCl + 0.05N $AlCl_3$	0.134	0.424	0.460*
2.	0.5N HNO_3	0.185	0.368	0.467*
3.	0.5N HCl	0.162	0.395	0.465*
4.	0.1N HCl	0.003	0.569*	0.426
5.	EDTA + $(NH_4)_2CO_3$	0.201	0.430	0.550*
6.	EDTA + NH_4OAc	0.138	0.393	0.424
7.	DTPA-TEA, pH 7.3	0.280	0.563*	0.673**
8.	1N NH_4OAc, pH 4.8	0.167	0.545*	0.597**

* : $P < .05$ ** : $P < .01$

solutions.

The data presented in Tables in 10 and 11, and in figures 2, 3, 4, 5, 6, and 7 show that Cu extracted with DTPA-TEA, pH 7.3, 0.1N HCl, and 1N NH_4OAc, pH 4.8 from air-dried and flooded soils was significantly related to the concentration of Cu in rice tissue. The data in Figure 5 show that the highest coefficient of correlation, r=0.603**, was found between the concentration of Cu in rice plants and DTPA-TEA extractable Cu on flooded soils. The 0.5N HCl+0.05N $AlCl_3$, 0.5N HNO_3, 0.5N HCl, EDTA+NH_4OAc, and EDTA+$(NH_4)_2CO_3$ extractants used for determining the Cu contents of the soils were not statistically related to the Cu concentration in rice plants.
The data presented in Table 10 show that statistically significant relationships were found between the uptake of Cu by plants and Cu extracted from the air-dried soils with six of the eight extracting solutions. No significant relationships were found between the uptake of Cu by rice and 0.1N HCl and EDTA+NH_4OAc extractable Cu from air-dried soils.

The data in Table 11 show that the uptake of Cu from flooded soils was significantly related to Cu extracted from the soils with the eight extractants. The relationships between the uptake of Cu by rice plants and extractable soil Cu are presented in Figures 8-21.

Table 11. Relationships as shown by simple correlation coefficients(r) between Cu contents extracted from 19 flooded soils with eight extracting solutions and dry matter production, Cu concentration, and Cu uptake by Saturn rice plants.

	Cu contents of soils extracted with	Dry matter production	Cu concentration	Cu uptake
		- - - - - - - r values	- - - - - - - -	
1.	0.5<u>N</u> HCl + 0.05<u>N</u> $AlCl_3$	0.289	0.305	0.523*
2.	0.5<u>N</u> HNO_3	0.286	0.380	0.577**
3.	0.5<u>N</u> HCl	0.303	0.348	0.565*
4.	0.1<u>N</u> HCl	0.246	0.484*	0.607**
5.	EDTA + $(NH_4)_2CO_3$	0.364	0.387	0.666**
6.	EDTA + NH_4OAc	0.330	0.330	0.564*
7.	DTPA-TEA, pH 7.3	0.271	0.603**	0.706**
8.	1<u>N</u> NH_4OAc, pH 4.8	0.265	0.500*	0.676**

* : P < .05   ** : P < .01

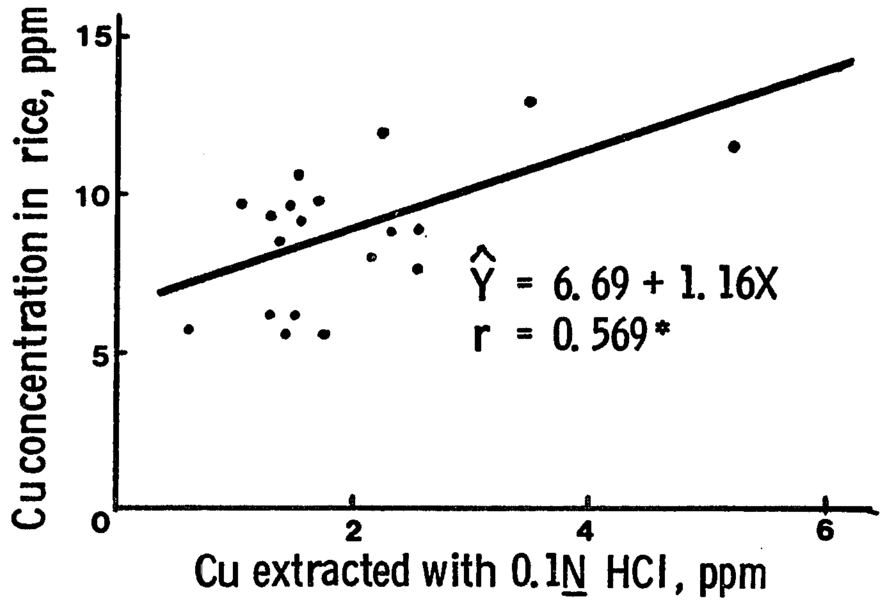

Figure 2. Relationship between Cu concentration in rice tissue and Cu content extracted with 0.1N HCl from air-dried soils. * $P < .05$

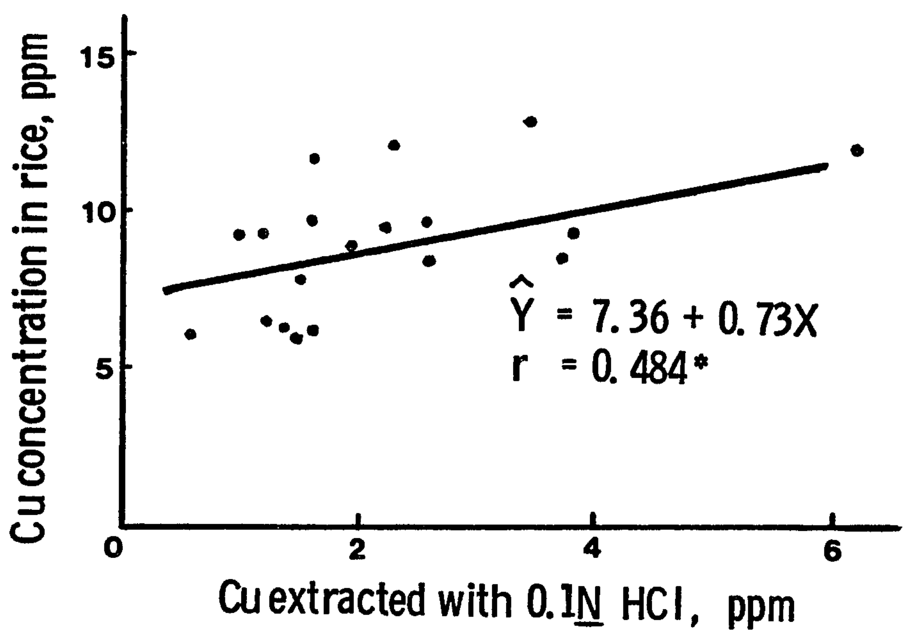

Figure 3. Relationship between Cu concentration in rice tissue and Cu content extracted with 0.1N HCl from flooded soils. * $P < .05$

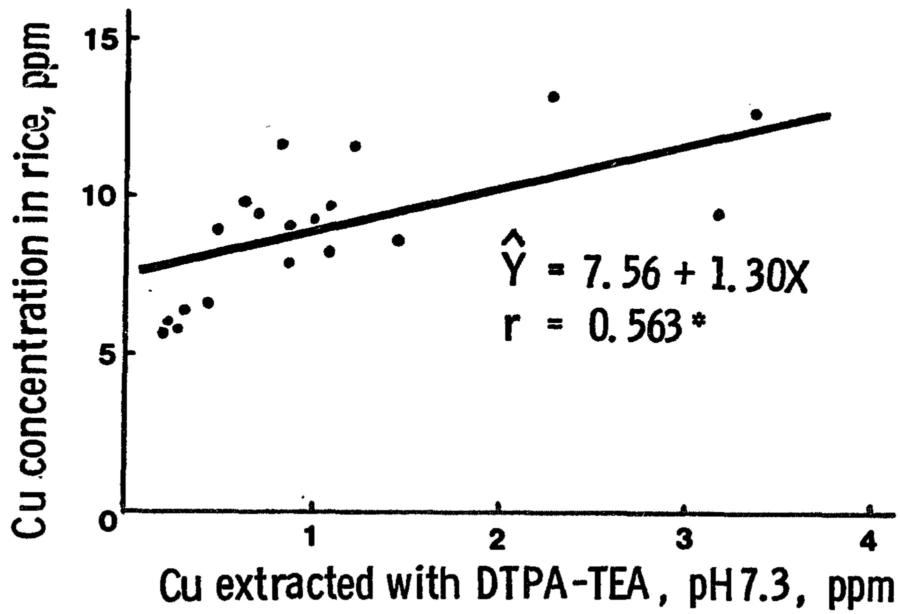

Figure 4. Relationship between Cu concentration in rice tissue and Cu content extracted with DTPA-TEA, pH 7.3 from air-dried soils. * $P < .05$

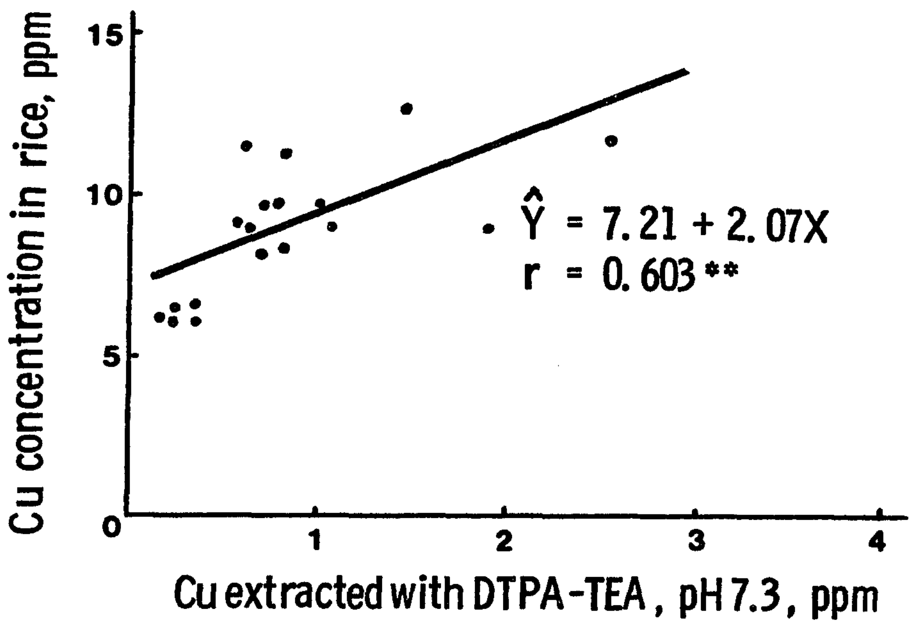

Figure 5. Relationship between Cu concentration in rice tissue and Cu content extracted with DTPA-TEA, pH 7.3 from flooded soils. ** $P < .01$

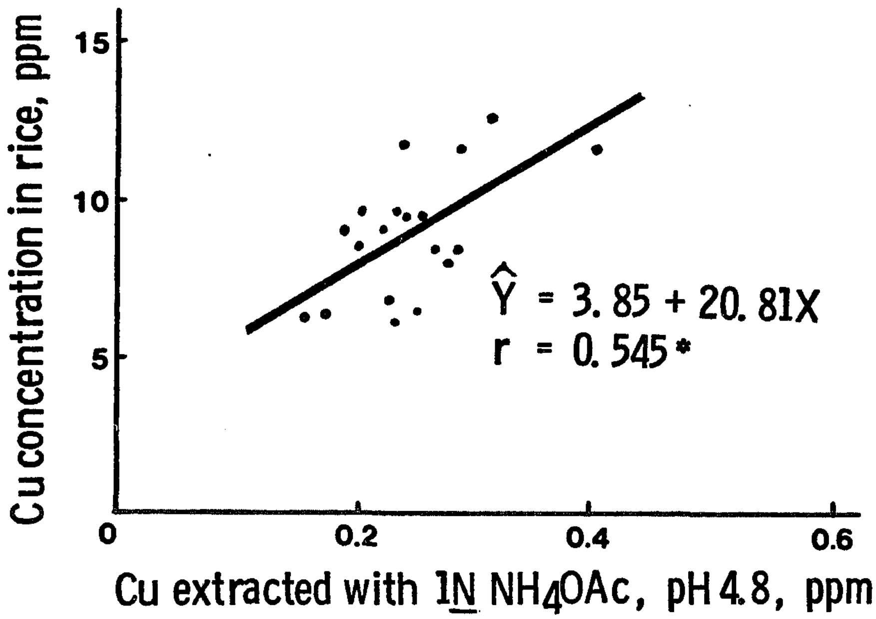

Figure 6. Relationship between Cu concentration in rice tissue and Cu content extracted with 1N NH_4OAc, pH 4.8 from air-dried soils. * $P < .05$

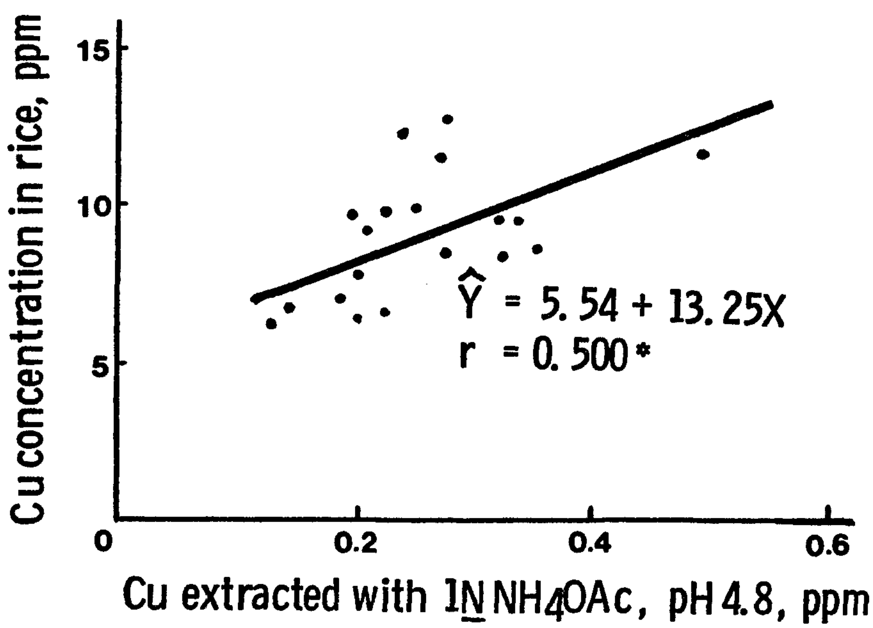

Figure 7. Relationship between Cu concentration in rice tissue and Cu content extracted with 1N NH_4OAc, pH 4.8 from flooded soils. * $P < .05$

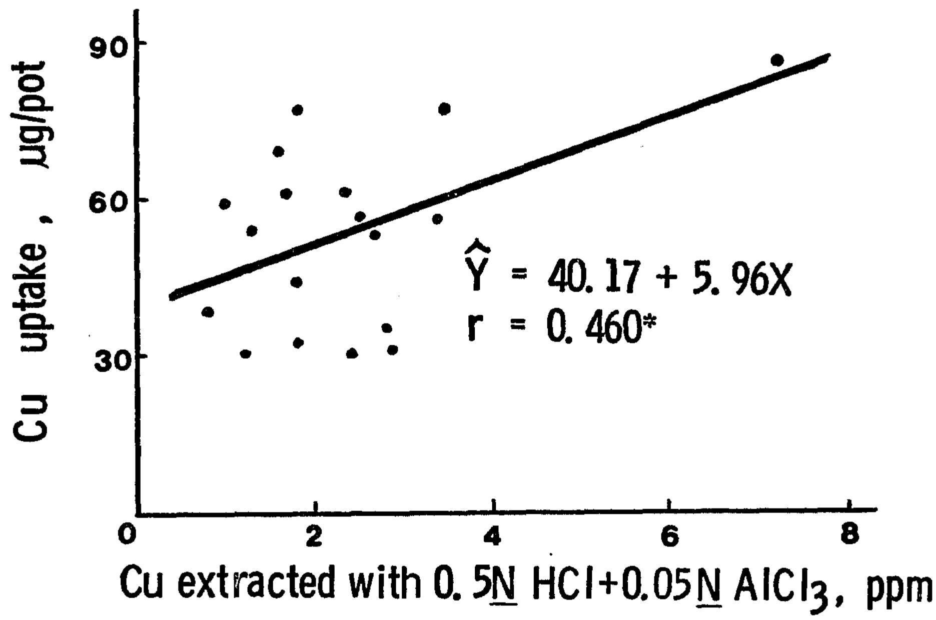

Figure 8. Relationship between Cu uptake by rice plants and Cu content extracted with 0.5N HCl+0.05N $AlCl_3$ from air-dried soils. * $P < .05$

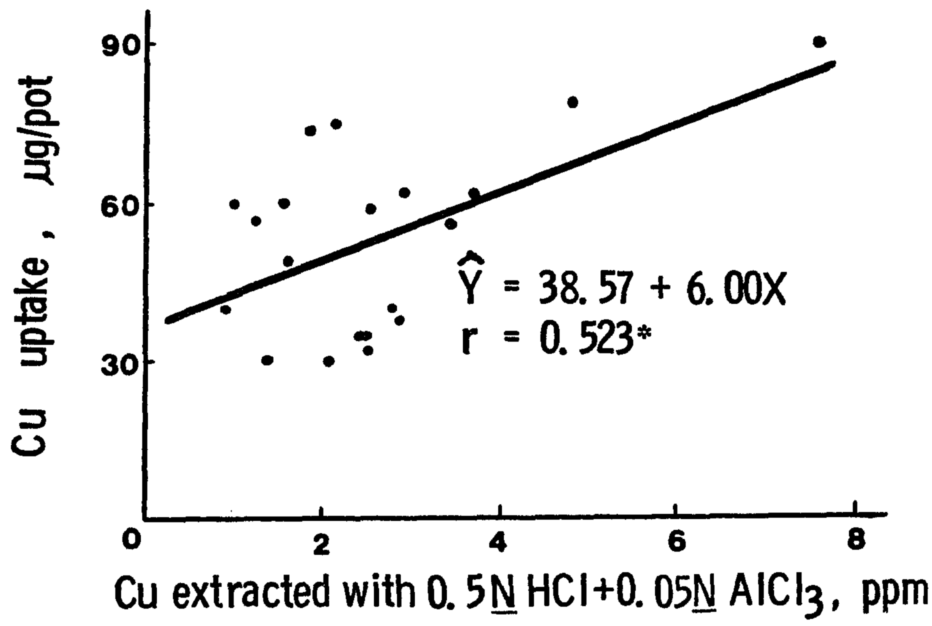

Figure 9. Relationship between Cu uptake by rice plants and Cu content extracted with 0.5N HCl+0.05N $AlCl_3$ from flooded soils. * $P < .05$

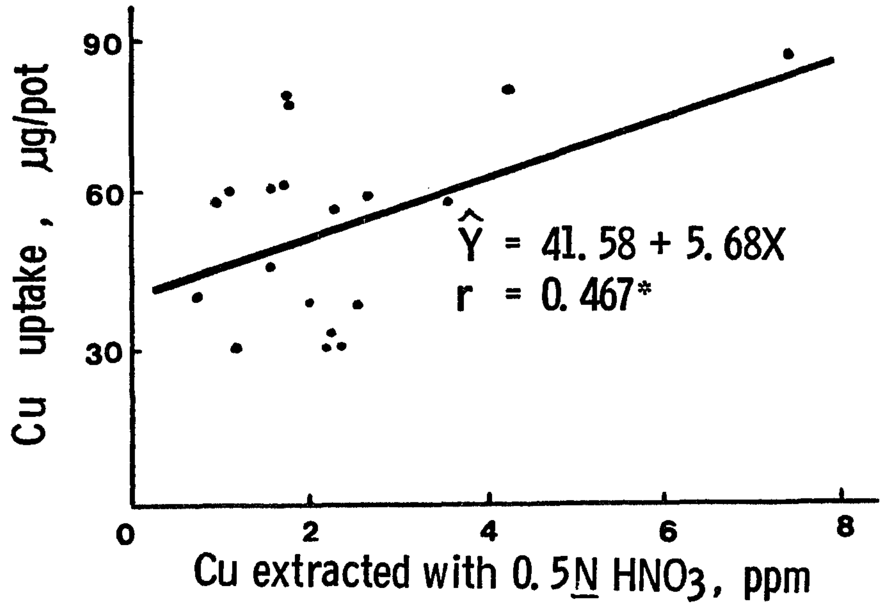

Figure 10. Relationship between Cu uptake by rice plants and Cu content extracted with 0.5N HNO_3 from air-dried soils. * $P < .05$

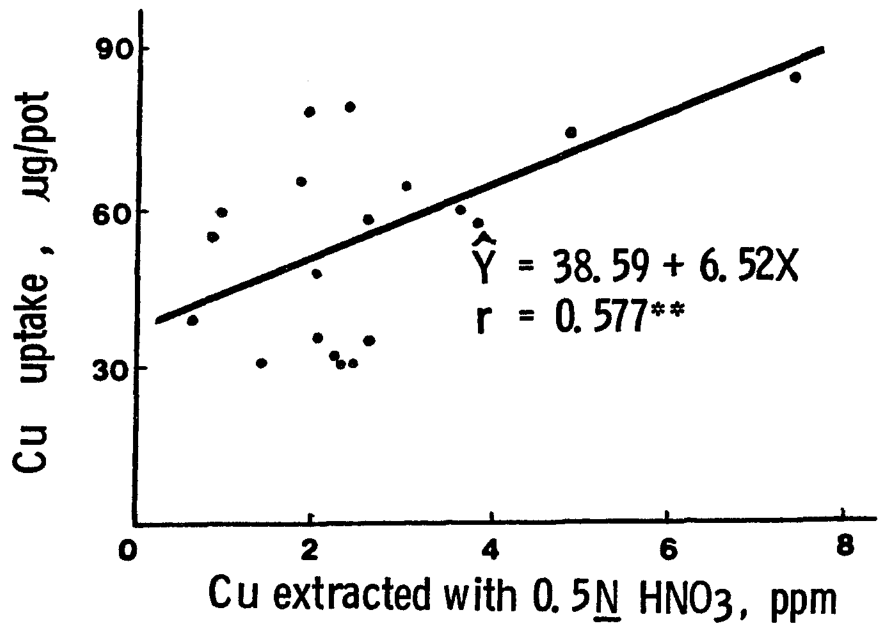

Figure 11. Relationship between Cu uptake by rice plants and Cu content extracted with 0.5N HNO_3 from flooded soils. ** $P < .01$

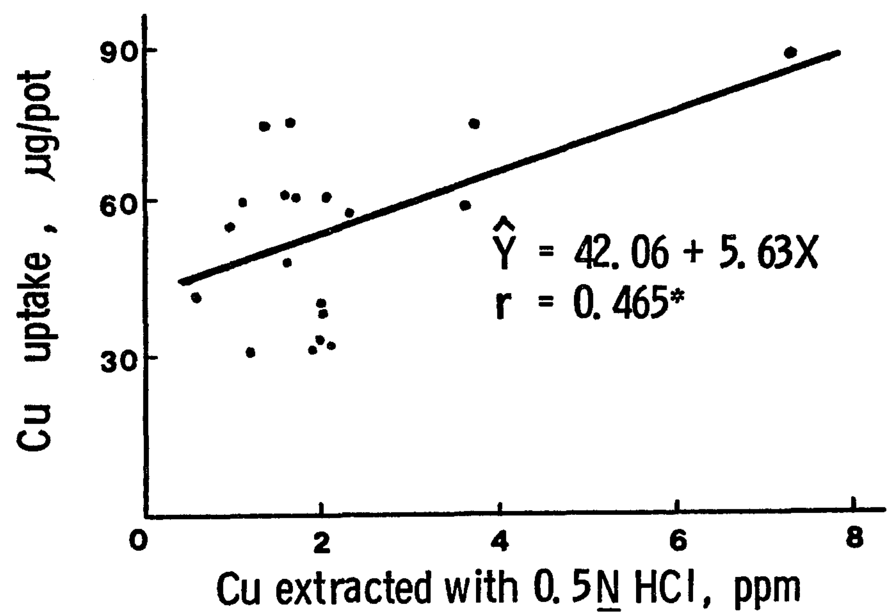

Figure 12. Relationship between Cu uptake by rice plants and Cu content extracted with 0.5$\underline{N}$ HCl from air-dried soils. * P < .05

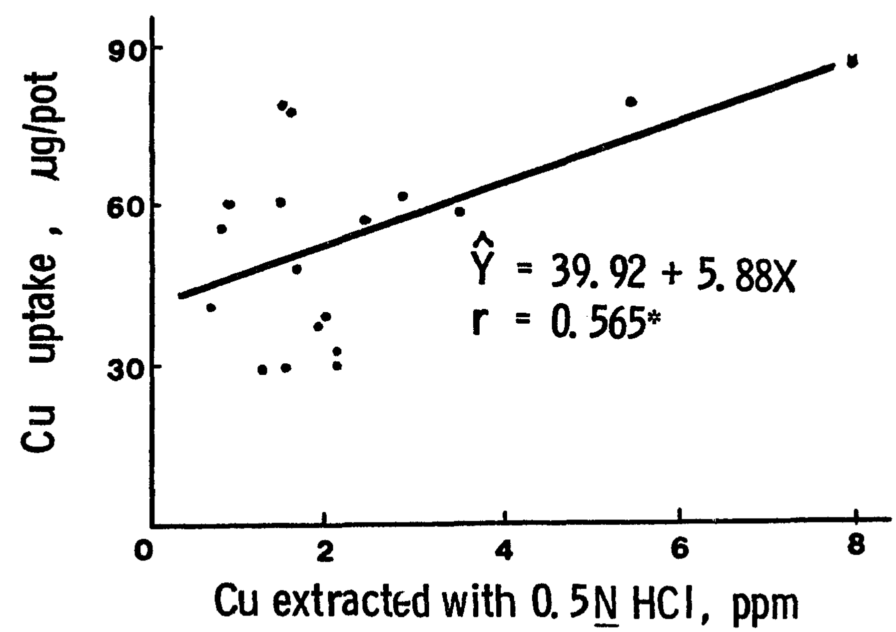

Figure 13. Relationship between Cu uptake by rice plants and Cu content extracted with 0.5$\underline{N}$ HCl from flooded soils. * P < .05

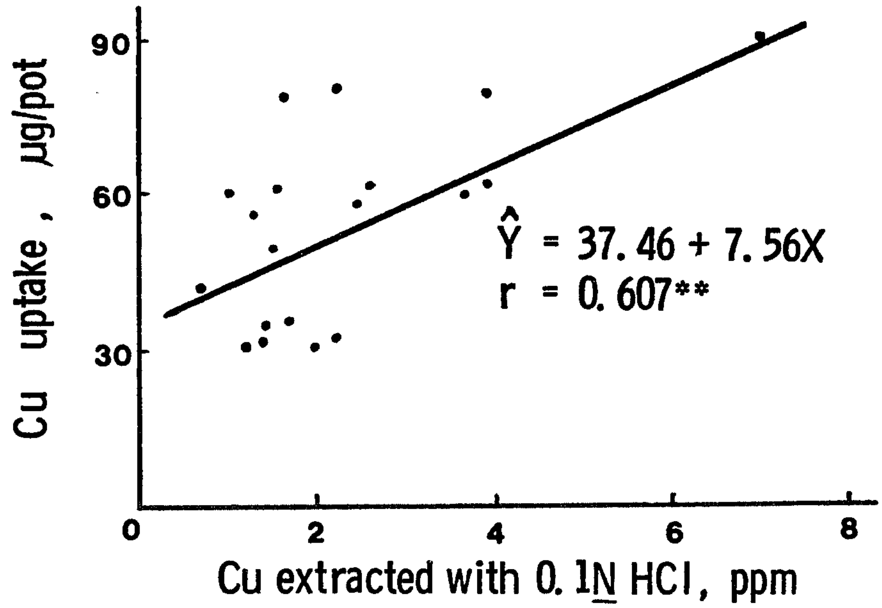

Figure 14. Relationship between Cu uptake by rice plants and Cu content extracted with 0.1N HCl from flooded soils. ** $P < .01$

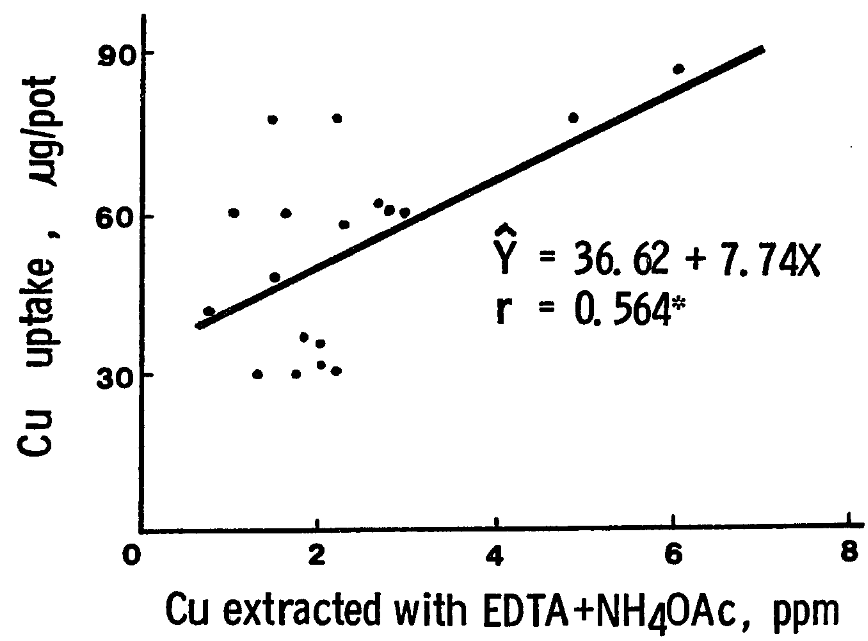

Figure 15. Relationship between Cu uptake by rice plants and Cu content extracted with EDTA+NH_4OAc from flooded soils. * $P < .05$

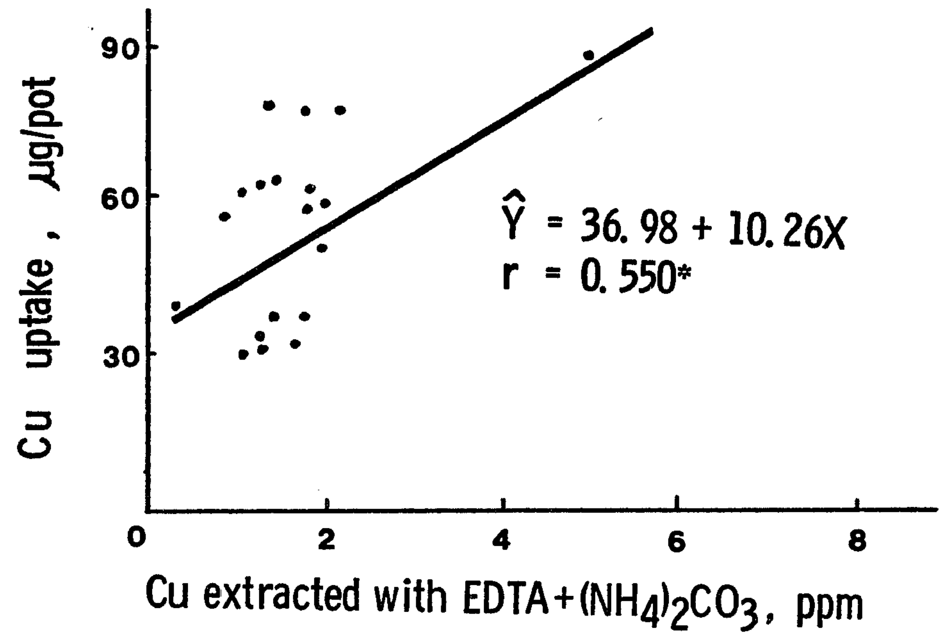

Figure 16. Relationship between Cu uptake by rice plants and Cu content extracted with EDTA+$(NH_4)_2CO_3$ from air-dried soils. * $P < .05$

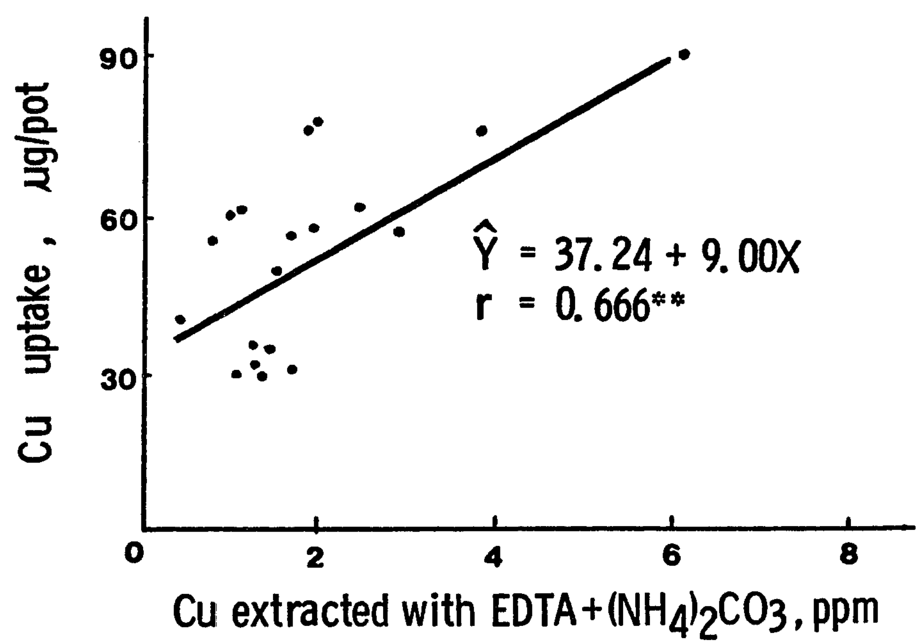

Figure 17. Relationship between Cu uptake by rice plants and Cu content extracted with EDTA+$(NH4)_2CO_3$ from flooded soils. ** $P < .01$

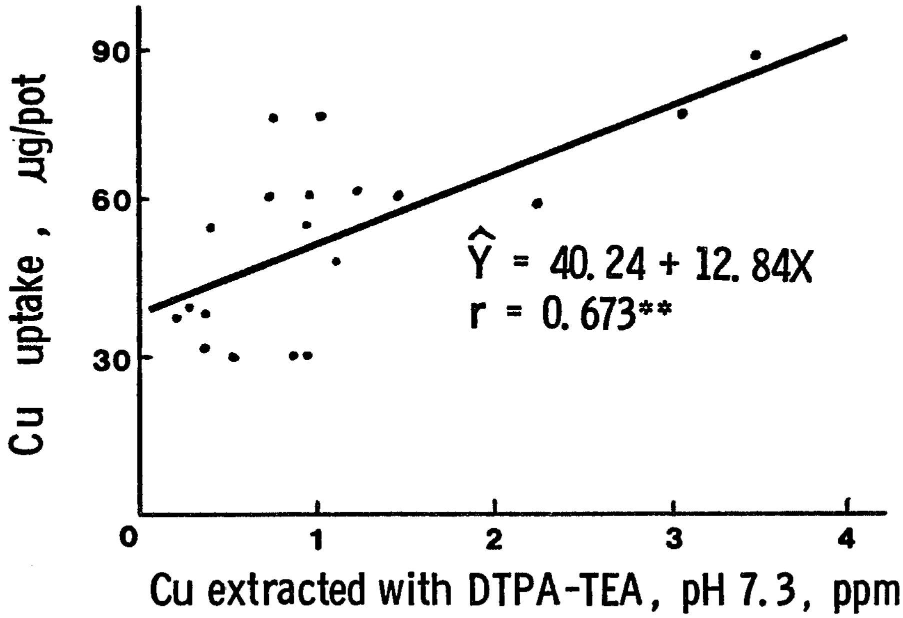

Figure 18. Relationship between Cu uptake by rice plants and Cu content extracted with DTPA-TEA, pH 7.3 from air-dried soils. ** P < .01

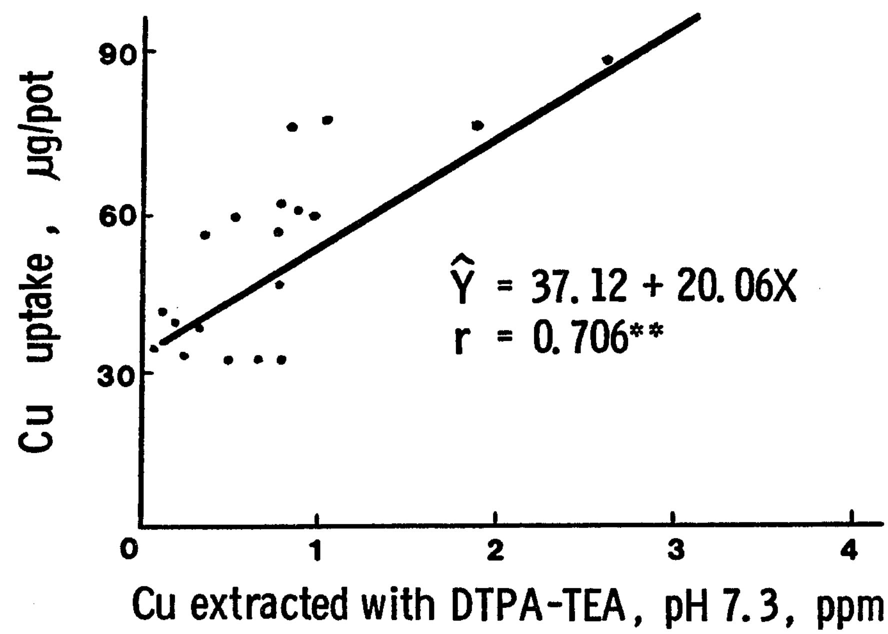

Figure 19. Relationship between Cu uptake by rice plants and Cu content extracted with DTPA-TEA, pH 7.3 from flooded soils. ** P < .01

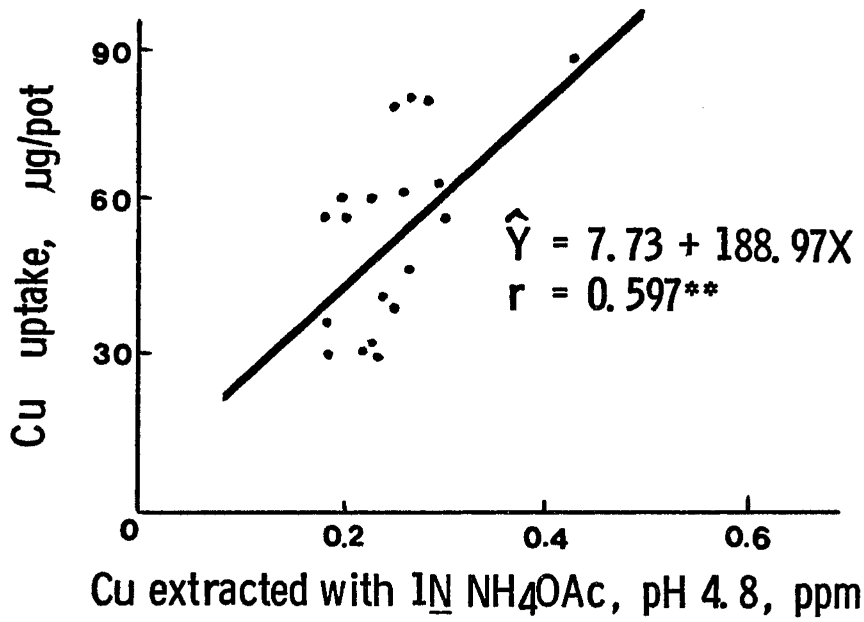

Figure 20. Relationship between Cu uptake by rice plants and Cu content extracted with 1N NH_4OAc, pH 4.8 from air-dried soils. ** $p < .01$

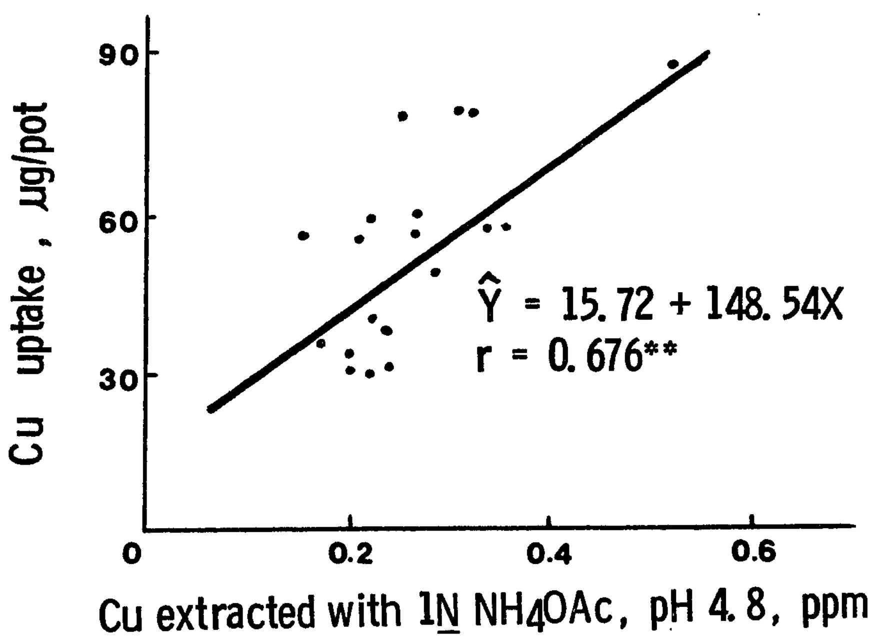

Figure 21. Relationship between Cu uptake by rice plants and Cu content extracted with 1N NH_4OAc, pH 4.8 from flooded soils. ** $p < .01$

Correlation analyses are often used as criteria for evaluating soil tests. Ozus and Hanway(1966) suggested that correlation studies should be conducted to provide the basis for selecting soil analyses that will provide the best index of neutrient availability. It is desirable that the amount of the plant nutrient extracted be proportional to that absorbed by the crop. Chemical values obtained by extraction have no absolute meaning concerning nutrient supply available to the root systems of plants. Therefore, they have meaning only as they are related to differences in plant growth or nutrient uptake(Cope and Rouse, 1973). The results obtained in the evaluation of the eight extractants indicated that the DTPA-TEA method was a satisfactory method for estimating the extractable Cu content of the soils used in this investigation.

Relationships as shown by simple correlation coefficients(r) and regression data between certain chemical properties of soils and dry matter production, Cu concentration, and Cu uptake by Saturn rice plants are presented in Table 12 and Figures 22-26. The data in Table 12 and Figures 22 and 23 show that the contents of K and organic matter were significantly correlated with the production of dry matter by rice plants.

Significant positive correlations were also found between the concentration of Cu in rice tissue and soil p,

Table 12. Relationships as shown by simple correlation coefficients(r) between certain chemical properties of soils and dry matter production, Cu concentration, and Cu uptake by Saturn rice plants.

	Soil chemical properties	Dry matter production	Cu concentration	Cu uptake
		- - - - - - - - - -	r values	- - - - - - - - -
1.	P	-0.060	0.595**	0.267
2.	Ca	0.324	0.026	0.317
3.	Mg	0.250	-0.087	0.199
4.	K	0.493*	-0.066	0.409
5.	Oragnic matter[1/]	0.513*	-0.561*	0.113
6.	pH, air-dried	-0.401	0.487*	-0.077
7.	pH, flooded	-0.201	0.428	0.029

* : $P < .05$ ** : $P < .01$

1/ Organic matter contents of Harris clay(soil No. 11) and Lafitte muck(soil No. 12) were not included in correlation ananyses.

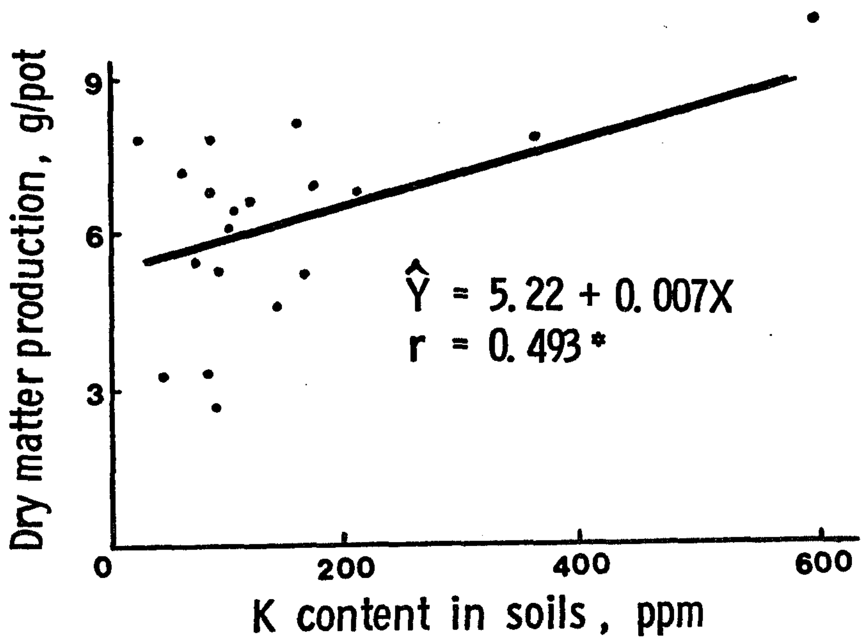

Figure 22. Relationship between dry matter production by rice plants and K content of soils. * P < .05

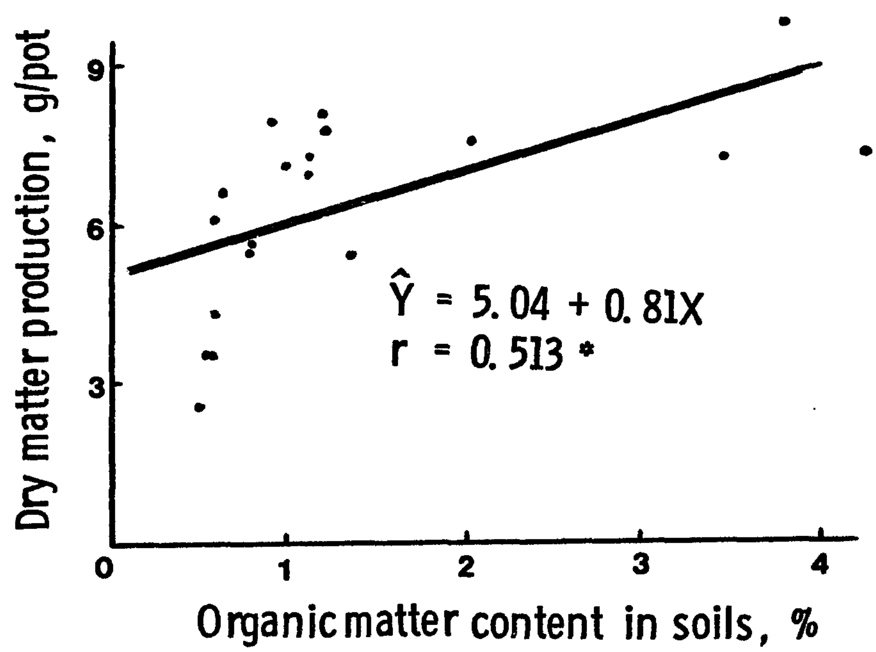

Figure 23. Relationship between dry matter production by rice plants and organic matter content of soils. * P < .05

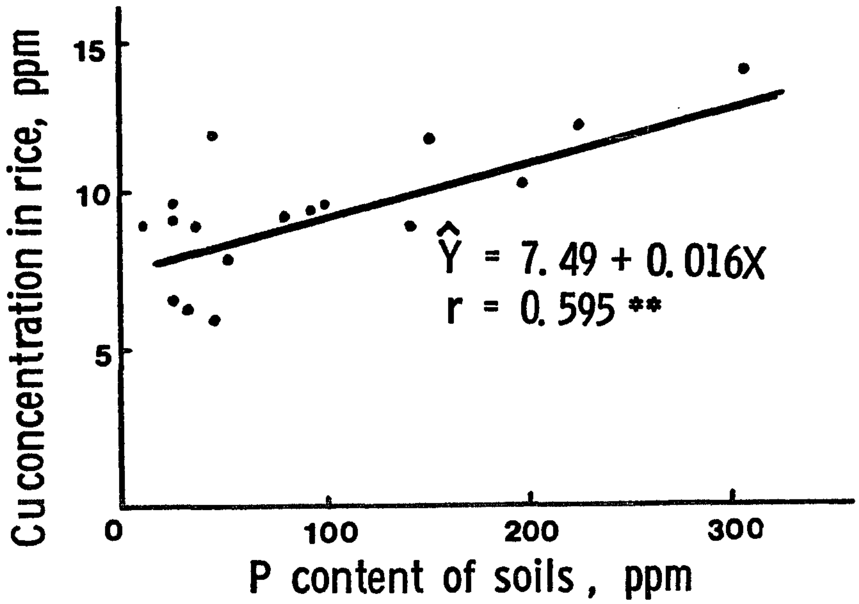

Figure 24. Relationship between Cu concentration in rice tissue and P content of soils. ** $P < .01$

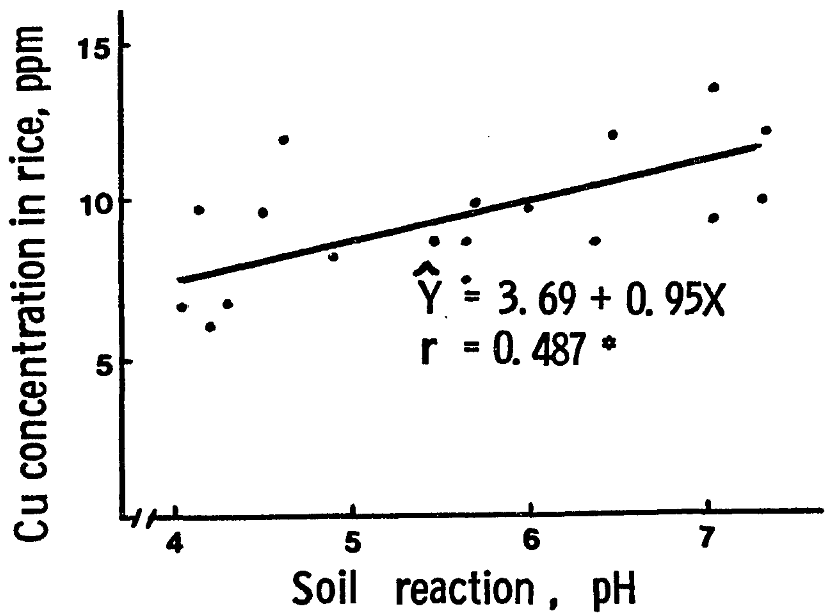

Figure 25. Relationship between Cu concentration in rice tissue and soil reaction(pH). * $P < .05$

and soil reaction(pH), as shown in Figures 24 and 25. The data show that as P content of soil increased there was corresponding increase in Cu concentration in rice tissue. As soil reaction increased from pH 4.1 to 7.4, the concentration of Cu in rice tissue also increased. One might conclude from these results that liming a soil would increase the availability of Cu. This is not the case since Cu uptake was not influenced by soil reaction.

A significant negative relationship was found between the concentration of Cu in rice tissue and the content of organic matter in soils, as shown in Figure 26. The data show that for each 1% increase in the organic matter content of the mineral soils from 0.53 to 4.38%, there was a corresponding decrease of approximately 1 ppm in the concentration of Cu in rice tissue. No significant relationships were found between the uptake of Cu by rice plants and the soil chemical properties measured.

Relationship between dry matter production and soil reaction is presented in Figure 27. The data show that a significant quadratic relationship was found between dry matter production and soil reaction(pH). Approximately 64% of the variability was accounted for by these two variables. The data also show that a significantly higher amount of dry matter was produced when the soil reaction varied between pH 5.0 and 6.0.

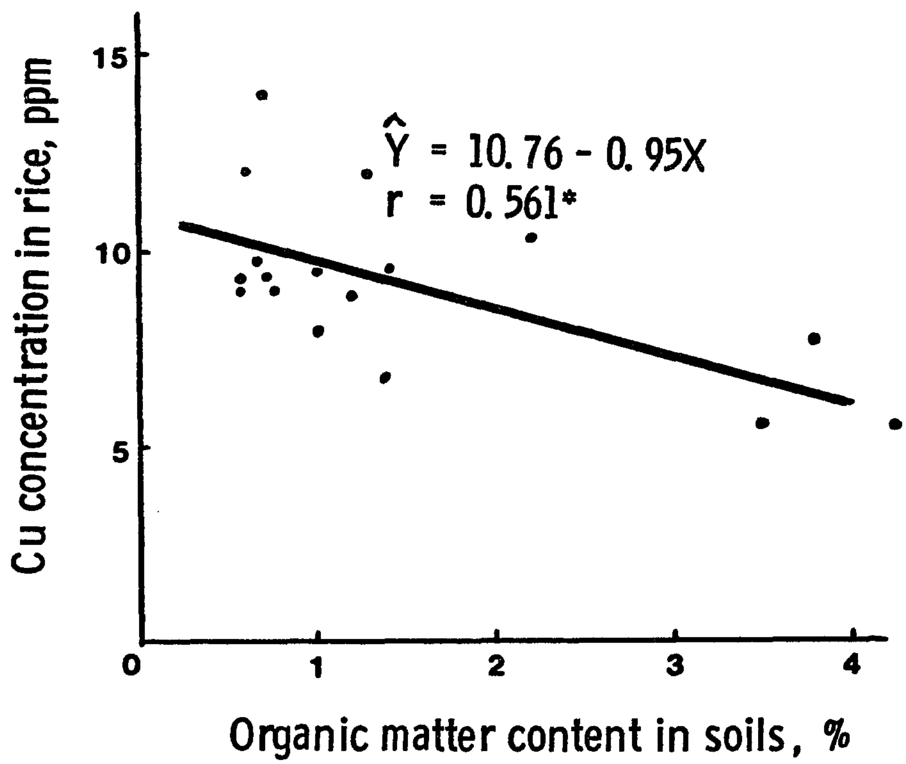

Figure 26. Relationship between Cu concentration in rice tissue and organic matter content of soils.
* P < .05

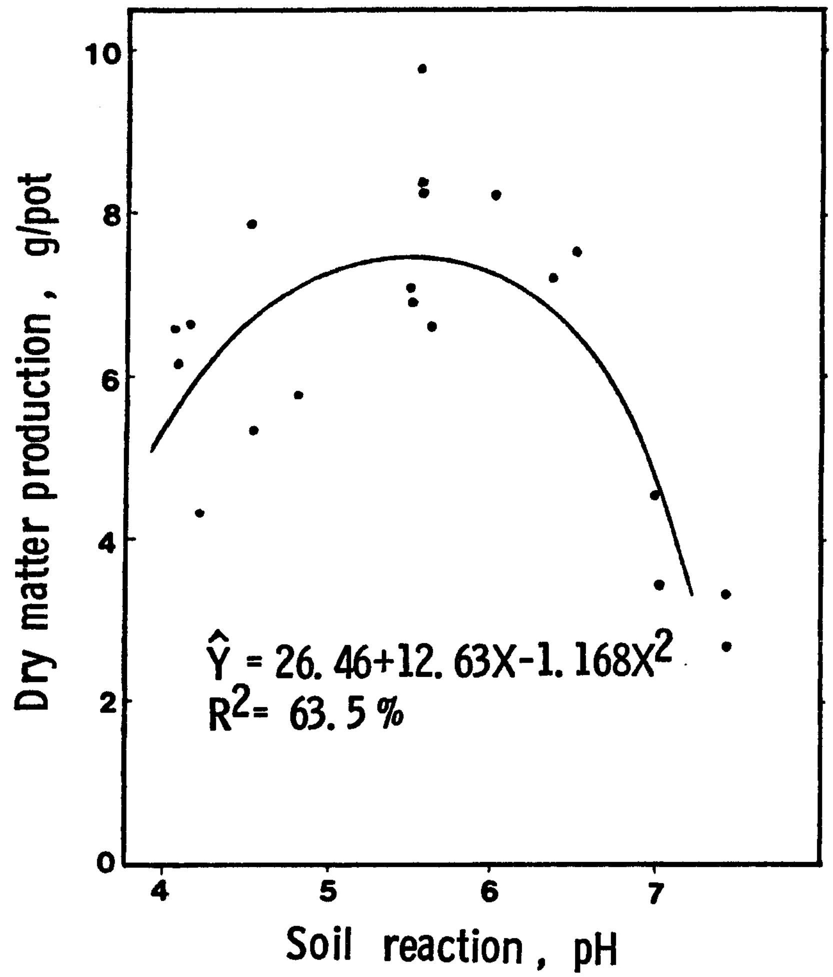

Figure 27. Relationship between dry matter production by rice plants and soil reaction(pH).

The relatively low correlation coefficients found between extractable soil Cu and the concentration of Cu in rice tissue indicated that the extractants used did not adequately measure the "availability" of soil Cu to rice plants. The inability to establish a significant relationship between soil Cu and plant Cu may have been due to the inherent chemical properties that existed in the soils selected for this investigation. Two variable multiple regression analyses were employed to determine if extractable Cu, together with the other soil chemical properties, would improve the prediction of the concentration of Cu in rice tissue.

Relationships as shown by regression data between extractable soil Cu in combination with soil organic matter and Cu concentration in rice tissue are presented in Table 13. The data show that multiple correlation coefficients of soil Cu in combination with soil organic matter resulted in an improvement in the prediction of the concentration of Cu in rice plant tissue. The regressions accounted for from 53.4 to 70.0% of the variations in the concentration of Cu in rice tissue.

Combinations of other chemical properties measured with extractable Cu did not significantly improve the predicability. The results indicate that all of the eight extractants could be used for determining soil Cu if the

Table 13. Relationships as shown by multiple correlation coefficients(R) and regression equations between Cu contents extracted from air-dried soils with eight extracting solutions in combination with soil organic matter contents and Cu concentrations in rice tissue.

Cu contents of soils extracted with(X_1), and soil O.M.(X_2)	Multiple correlation coefficient	Regression equation	Coefficient of determination
	R		R^2(%)
1. 0.5N HCl + 0.01N $AlCl_3$	0.763**	$\hat{Y} = 9.14+0.72X_1-1.04X_2$	58.2
2. 0.5N HNO_3	0.777**	$\hat{Y} = 9.39+0.71X_1-1.12X_2$	60.3
3. 0.5N HCl	0.774**	$\hat{Y} = 9.41+0.70X_1-1.09X_2$	59.9
4. 0.1N HCl	0.772**	$\hat{Y} = 8.67+0.98X_1-0.89X_2$	59.6
5. EDTA + 1N $(NH_4)_2CO_3$	0.731**	$\hat{Y} = 9.14+0.94X_1-0.96X_2$	53.4
6. EDTA + 1N NH_4OAc	0.771**	$\hat{Y} = 9.01+0.92X_1-1.07X_2$	59.9
7. DTPA-TEA, pH 7.3	0.817**	$\hat{Y} = 9.42+1.30X_1-1.11X_2$	66.8
8. 1N NH_4OAc, pH 4.8	0.837**	$\hat{Y} = 5.57+21.3X_1-1.10X_2$	70.0

** $P < .01$.

Table 14. Relationships as shown by simple correlation coefficients(r) among eight extracting solutions for determining Cu contents of 19 air-dried soils.

	0.5N HNO_3	0.5N HCl	0.1N HCl	EDTA+ $(NH_4)_2CO_3$	EDTA+ NH_4OAc	DTPA-TEA pH 7.3	1N NH_4OAc pH 4.8
	- - - - - - - - - -	r values	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -
1. 0.5N HCl+ 0.05N $AlCl_3$	0.986**	0.992**	0.953**	0.952**	0.978**	0.836**	0.756**
2. 0.5N HNO_3		0.996**	0.917**	0.938**	0.985**	0.847**	0.769**
3. 0.5N HCl			0.936**	0.947**	0.988**	0.844**	0.764**
4. 0.1N HCl				0.910**	0.924**	0.791**	0.732**
5. EDTA+$(NH_4)_2CO_3$					0.921**	0.794**	0.799**
6. DETA+NH_4OAc						0.850**	0.719**
7. DTPA-TEA, pH 7.3							0.771**

** : $P < .01$

Table 15. Relationships as shown by simple correlation coefficients(r) among eight extracting solutions for determining Cu contents of 19 flooded soils.

	0.5N HNO_3	0.5N HCl	0.1N HCl	EDTA+ $(NH_4)_2CO_3$	EDTA+ NH_4OAc	DTPA-TEA pH 7.3	1N NH_4OAc pH 4.8
	r values						
1. 0.5N HCl+ 0.05N $AlCl_3$	0.992**	0.991**	0.955**	0.958**	0.972**	0.865**	0.800**
2. 0.5N HNO_3		0.992**	0.966**	0.974**	0.977**	0.902**	0.834**
3. 0.5N HCl			0.959**	0.970**	0.983**	0.890**	0.812**
4. 0.1N HCl				0.957**	0.935**	0.919**	0.894**
5. EDTA+$(NH4)_2CO_3$					0.955**	0.914**	0.894**
6. EDTA+NH_4OAc						0.884**	0.789**
7. DTPA-TEA, pH 7.3							0.842**

** : $P < .01$

content of soil organic matter was included in the regression analyses.

Relationships as shown by simple correlation coefficients(r) among eight extracting solutions for determining Cu contents of air-dried and flooded soils are presented in Tables 14 and 15. Highly significant correlations were found for paired comparisons of all extraction methods for flooded and air-dried soils.

The effects of flooding periods on the soil reaction, and 0.1*N* HCl and DTPA-TEA extractable Cu in five soils are presented in Table 16. The pH of Alligator clay(soil No. 2) and Falaya silt loam(soil No.8) approached neutrality, while no appreciable changes in soil pH were noted on the other soils. The data show that increase in flooding periods tended to decrease 0.1*N* HCl extractable Cu on Beauregard silt loam(soil No.3), Chastain clay(soil No.5), and Crowley silt loam(soil No.6). Progressively larger amounts of Cu were extracted by 0.1*N* HCl from Alligator clay and Falaya silt loam as flooding periods were increased from 0 to six weeks.

The data in Table 16 also show that increasing the flooding times from 0 to six weeks tended to decrease the DTPA-TEA extractable Cu from all of the soils. The kinetics of 0.1*N* HCl and DTPA-TEA extractable Cu in five flooded soils are presented in Figure 28.

Table 16. The effects of flooding periods on the soil reaction(pH), and Cu contents of five soils extracted with 0.1N HCl and DTPA-TEA, pH 7.3.

	Flooding periods (weeks)				
	0	1	2	4	6
Alligator clay(soil No. 2)					
pH	5.7	5.9	6.2	6.5	6.6
Cu, 0.1N HCl, ppm	2.10	2.84	3.26	3.74	3.80
Cu, DTPA-TEA, ppm	3.20	3.18	2.64	2.06	1.81
Beauregard silt loam (soil No. 3)					
pH	5.7	5.7	5.7	5.9	5.9
Cu, 0.1N HCl, ppm	1.35	1.36	1.31	1.31	1.24
Cu, DTPA-TEA, ppm	0.42	0.42	0.39	0.34	0.34
Chastain clay (soil No. 5)					
pH	4.2	4.2	4.2	4.3	4.4
Cu, 0.1N HCl, ppm	1.90	1.94	1.88	1.79	1.74
Cu, DTPA-TEA, ppm	0.30	0.29	0.31	0.26	0.21
Crowley silt loam(soil No. 6)					
pH	7.4	7.5	7.5	7.6	7.6
Cu, 0.1N HCl, ppm	2.20	2.20	2.14	2.00	1.98
Cu, DTPA-TEA, ppm	0.90	0.85	0.78	0.68	0.72
Falaya silt loam(soil No. 8)					
pH	5.5	5.9	6.5	6.8	6.9
Cu, 0.1N HCl, ppm	2.45	2.63	3.27	3.66	3.77
Cu, DTPA-TEA, ppm	1.46	1.40	1.24	1.00	1.00

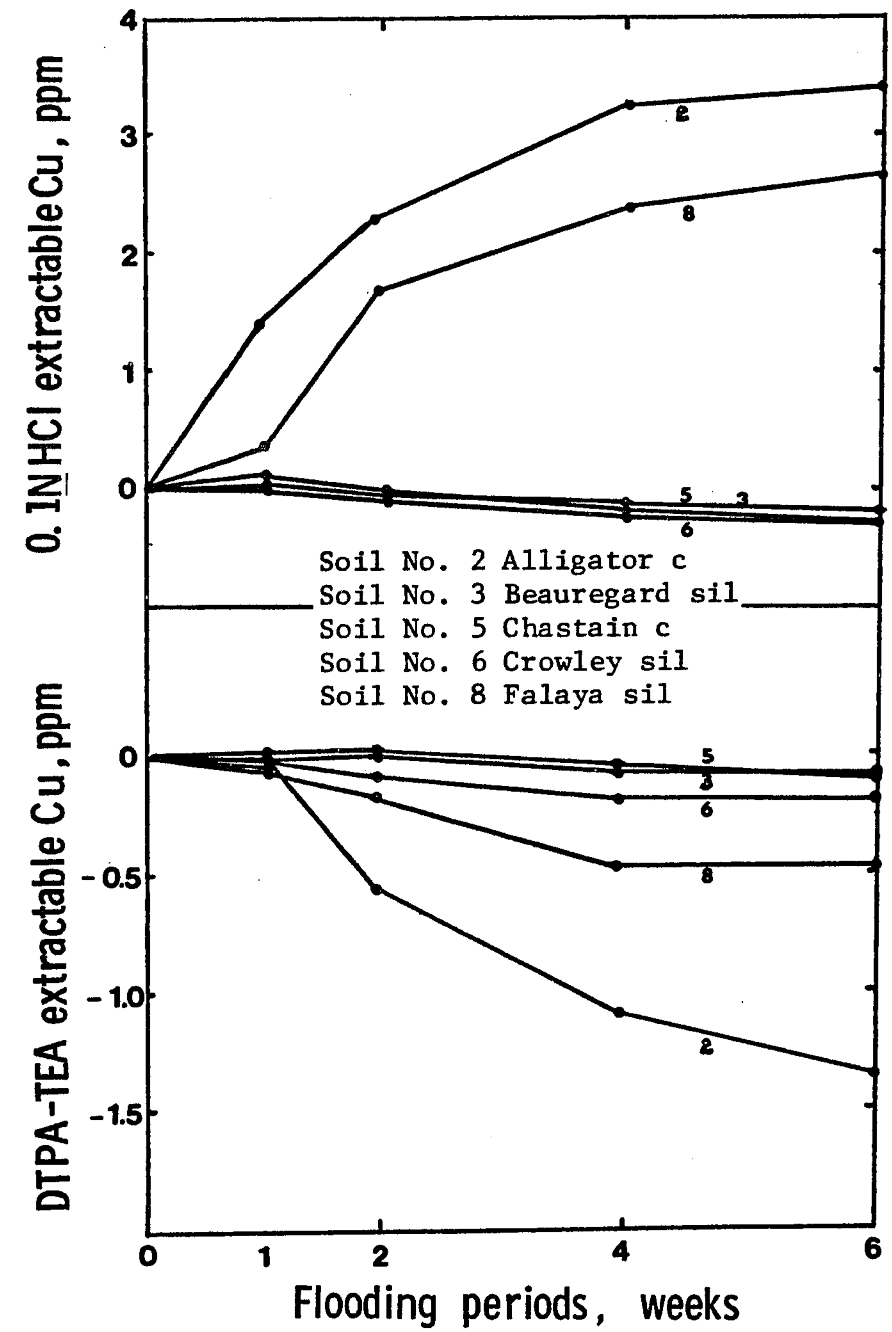

Figure 28. Kinetics of 0.1N HCl and DTPA-TEA extractable Cu in five flooded soils.

The effects of flooding periods on DTPA-TEA extractable Zn, Mn, and Fe contents in five flooded soils are presented in Table 17. The data show that in general, the DTPA-TEA extractable Zn decreased progressively as flooding periods were increased. The decrease in DTPA-TEA extractable Zn in flooded soils was similar to the results obtained with DTPA-TEA extractable Cu, and agrees with the results reported by Giordano and Mortvedt(1972), and Sedberry, et al.(1978).

The DTPA-TEA extractable Mn and Fe contents of all of the soils increased on flooding. The more pronounced increases in extractable Mn and Fe were noted in Alligator clay and Falaya silt loam. The kinetics of DTPA-TEA extractable Zn, Mn, and Fe in five flooded soils are presented in Figures 29 and 30.

Transforamtions of Mn and Fe in flooded soils have been well established(Patrick,1964; Redman and Patrick, 1965; Motomura,1969; Ponnamperuma,1977). The results obtained in this investigation suggest that the Alligator and Falaya soils contained larger amounts of reducible Mn and Fe than did the other soils. The results also suggest that Cu may also exist in an occluded form in soils containing large amounts of Mn and Fe oxides, and flooding the soil causes reduction of these oxides to Mn^{2+} and Fe^{2+} with subsequent release of a part of the

Table 17. The effects of flooding periods on the DTPA-TEA extractable Zn, Mn, and Fe contents of five soils.

	Flooding periods(weeks)				
	0	1	2	4	6
	- - - -		ppm	- - - -	
Alligator clay(soil No.2)					
Zn	5.16	4.98	3.18	2.00	1.82
Mn	32.6	98.5	105.2	98.5	95.0
Fe	105.0	288.5	414.5	466.0	433.2
Beauregard silt loam(soil No. 3)					
Zn	1.12	0.94	0.93	0.78	0.75
Mn	5.5	10.9	11.3	10.4	9.5
Fe	27.2	36.1	41.8	34.7	29.8
Chastain clay(soil No. 5)					
Zn	2.11	2.23	1.91	1.65	1.60
Mn	16.8	23.2	29.4	27.1	27.0
Fe	120.0	130.3	157.2	153.0	132.0
Crowley silt loam(soil No. 6)					
Zn	0.58	0.54	0.51	0.43	0.45
Mn	11.5	16.0	18.5	17.9	15.0
Fe	12.4	13.0	15.1	14.0	14.2
Falaya silt loam(soil No. 8)					
Zn	3.02	1.86	0.96	1.08	0.88
Mn	248.5	405.4	432.6	402.6	417.8
Fe	72.8	97.9	181.6	197.2	176.9

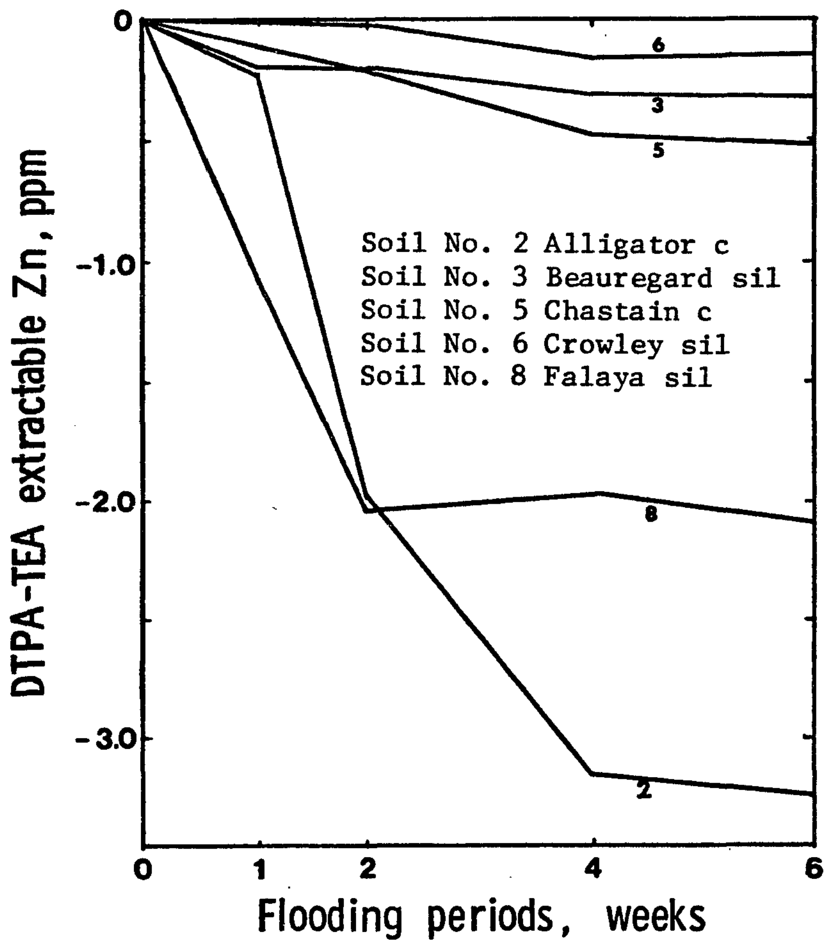

Figure 29. Kinetics of DTPA-TEA extractable Zn in five flooded soils.

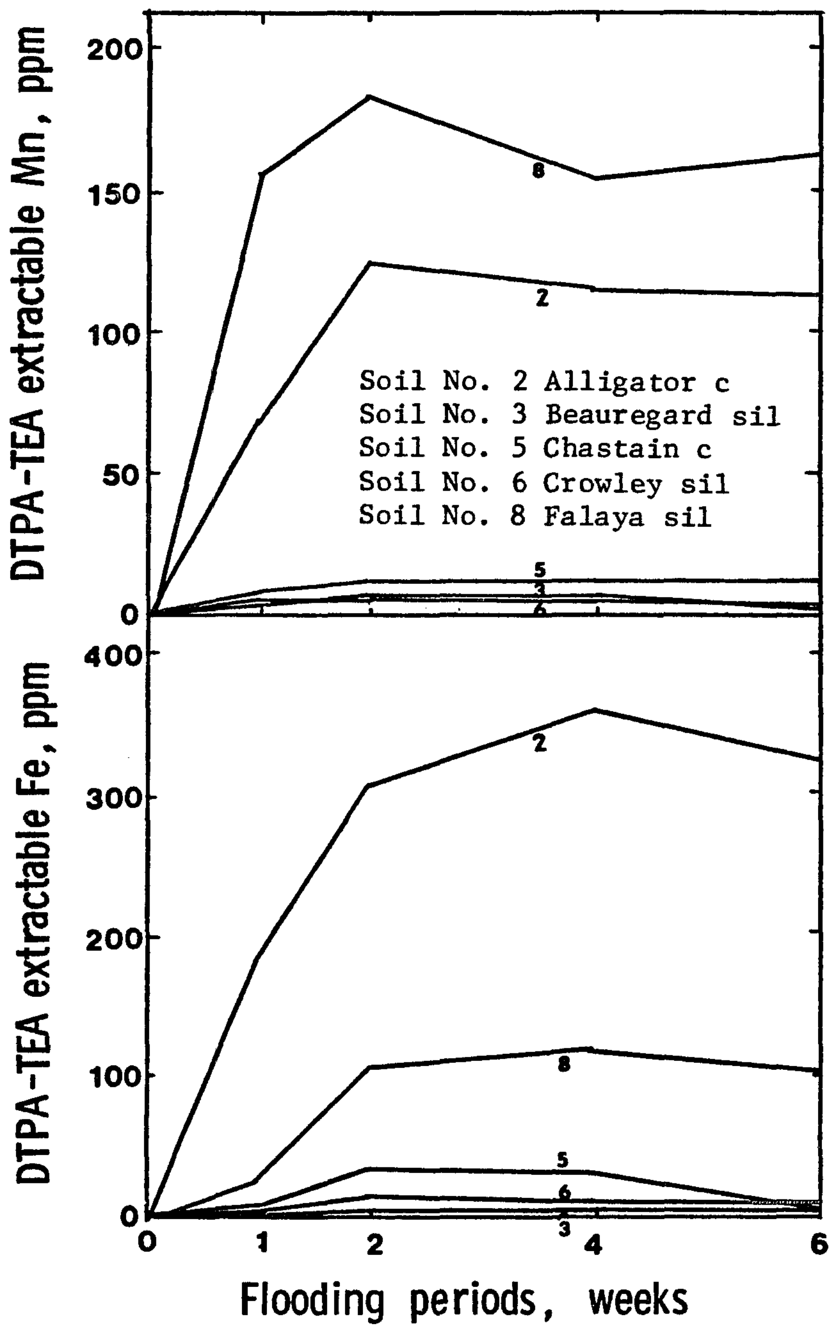

Figure 30. Kinetics of DTPA-TEA extractable Mn and Fe in five flooded soils.

occluded Cu(Jenne, 1968; Ponnamperuma, 1977). The increased amounts of 0.1N HCl extractable Cu in the Alligator and Falaya soils were attributed to surface reactions brought about by reduction or to the pH increases accompanying reduction(Ponnamperuma, 1977).

The observed decreases in DTPA-TEA extractable Cu and Zn may be attributed to pH increases(Lindsay, 1972; Ponnamperuma, 1977), or precipitation of insoluble carbonate or sulfide by organic matter decomposition under reduced conditions(IRRI, 1969, 1970; Hem, 1972; Kittrick, 1976; Reddy and Patrick, 1977).

The effects of rates of Cu on dry matter production, concentration of Cu, Zn, Mn, and Fe in rice tissue, and Cu uptake by rice plants grown on Myatt fine sandy loam and Lafitte muck are presented in Table 18. The data show that Cu rates did not significantly influence dry matter production on Myatt fine sandy loam(soil No. 15). The application of 5 ppm of Cu to Lafitte muck(soil No. 12) resulted in a significant increase over the control in dry matter production.

The data in Table 18 show that the concentration and uptake of Cu by the plants grown on the two soils significantly increased with increasing rates of applied Cu. The application of 5 ppm of Cu to the Myatt soil resulted in a significant increase in the concentration of Zn in

Table 18. The effects of application rates of Cu on dry matter production, concentration of Cu, Zn, Mn, and Fe in plant tissue, and Cu uptake by Saturn rice plants grown on Myatt fine sandy loam and Lafitte muck.

Rate of[1/] Cu	Dry matter	Concentration				Cu uptake
		Cu	Zn	Mn	Fe	
ppm	g/pot	ppm				µg/pot
Myatt fine sandy loam(soil No. 15)						
0	5.7	6.46	27.5	1,063	70.5	43.3
5	6.9	11.55	38.0	1,171	73.3	79.4
10	6.5	15.35	33.9	1,131	76.5	100.0
20	6.2	23.33	34.1	1,184	77.6	143.7
LSD, 5%	ns	1.96	5.9	ns	ns	16.9
Lafitte muck(soil No. 12)						
0	5.1	5.41	53.5	823	102.3	27.6
5.	5.9	9.23	57.2	799	107.3	54.1
10	5.6	11.72	56.7	795	117.1	65.0
20	5.4	14.75	58.3	772	109.3	79.3
LSD, 5%	0.4	1.74	ns	ns	13.2	12.7

1/ Cu was applied to soil at the rates equivalent to 0, 5, 10, and 20 ppm as $CuSO_4 \cdot 5H_2O$, 25% Cu.

rice plant tissue. However, no significant influence of applied Cu on the concentration of Zn in rice tissue was observed on Lafitte muck.

The Cu treatment had no significant influence on the concentration of Mn in plant tissue. Application of 10 ppm of Cu to Lafitte muck resulted in a significant increase in the concentration of Fe in rice tissue. The Cu treatment had no significant influence on the concentration of Fe in the tissue of rice plants grown on the Myatt soil.

A physiological disorder of rice plants grown on Myatt fine sandy loam was observed. Young leaves of rice plants grown on the soil that received an application of 10 ppm of Cu were slightly chlorotic. Severe chlorosis was noted on plants that were grown on the soil that received 20 ppm of Cu. The chlorosis was first observed four weeks after seeding and became more severe with time. Chlorosis was not observed when no Cu was applied or when 5 ppm of Cu was used on Myatt fine sandy loam. The rice plants grown on Lafitte muck did not exhibit chlorosis regardless of Cu treatments.

The effects of rates of Cu on Zn:Cu and Fe:Cu ratios in rice tissue in relation to chlorosis are presented in Figure 31. Plants grown on Myatt fine sandy loam at 20 ppm of applied Cu had Zn:Cu and Fe:Cu ratios of 1.46 and 3.33, respectively, and were severely chlorotic. Plants grown

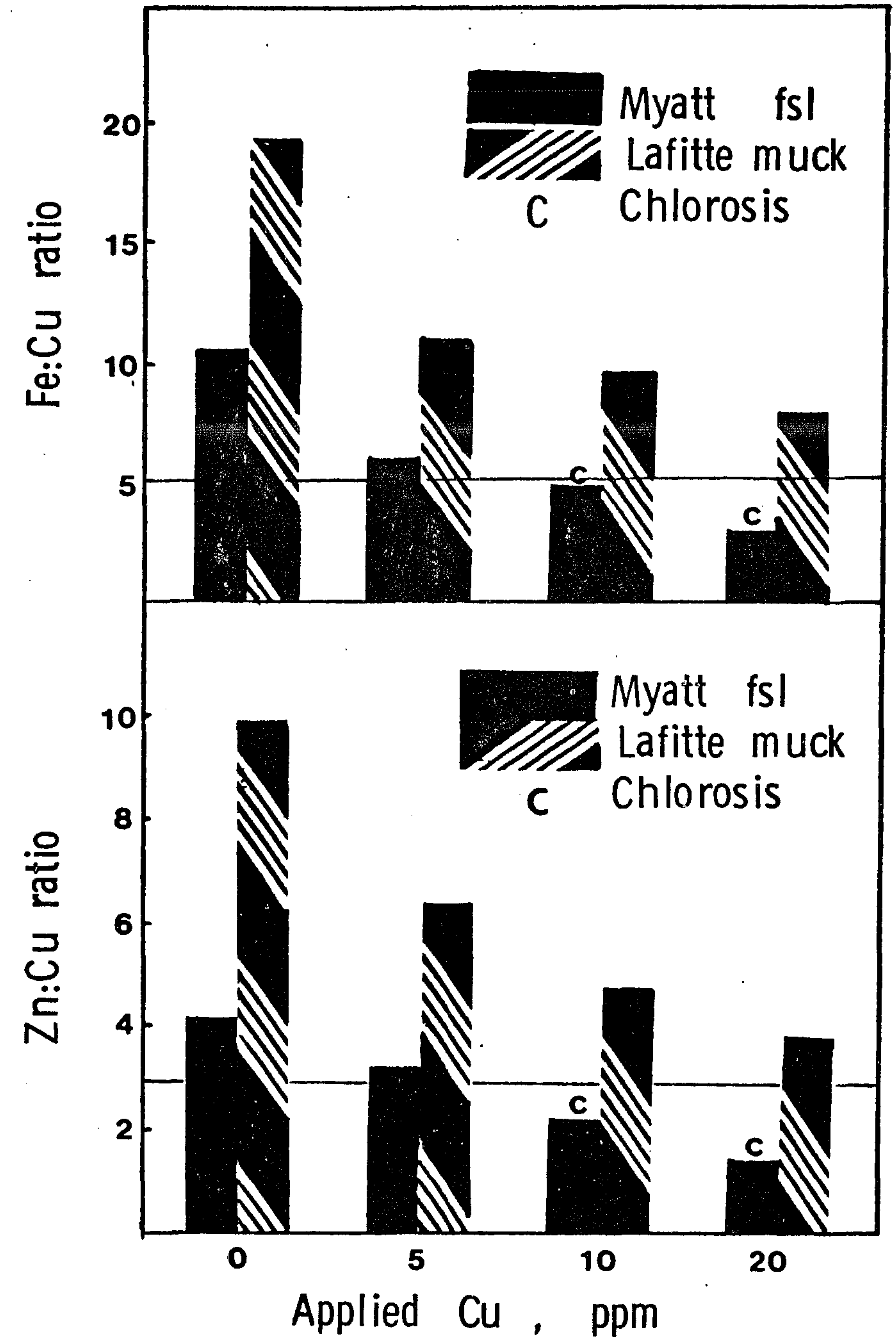

Figure 31. The effects of rates of Cu on Zn:Cu and Fe:Cu ratios in rice tissue grown on Myatt fine sandy loam and Lafitte muck in relation to leaf chlorosis.

at 10 ppm of applied Cu had Zn:Cu and Fe:Cu ratios of 2.21 and 4.98, respectively, and were only slightly chlorotic. The Zn:Cu and Fe:Cu ratios in plants grown at 5 ppm of Cu were 3.29 and 6.35, respectively and were not chlorotic. The lower Zn:Cu and Fe:Cu ratios of 3.95 and 7.41, respectively, occurred in the plants grown on Lafitte muck at 20 ppm of applied Cu. No chlorosis was observed. The data indicate that the plants in which Zn:Cu and Fe:Cu ratios were lower than about 3.0 and 5.0, respectively, exhibited chlorotic symptoms. The data also indicate that an optimum nutritional balance may be necessary for normal plant growth. The results suggest that chlorosis may have been due partially to Zn:Cu and Fe:Cu ratios rather than the concentration of Cu, Zn, or Fe in rice plant tissue.

The effects of application rates of Cu on the soil Cu extracted from Myatt fine sandy loam and Lafitte muck with five extracting solutions are presented in Table 19. The application of increasing rates of Cu resulted in increases in the level of soil-test Cu determined with the five methods of extraction.

The percent recovery of applied Cu as an average of four rates by five extractants from Myatt fine sandy loam and Lafitte muck in presented in Table 20 and Figure 32. Consistently higher percentages of applied Cu were

Table 19. The effects of application rates of Cu on the Cu contents extracted from Myatt fine sandy loam and Lafitte muck with five extracting solutions.

Rate of[1/] Cu	HCl+ $AlCl_3$	0.5N HCl	0.1N HCl	DTPA-TEA pH 7.3	NH_4OAc pH 4.8
ppm	- - - - - - - - - - - -	ppm	- - - - - - - - - - - -		
- - - - - - Myatt fine sandy loam(soil No. 15) - - - - - - - -					
0	1.54	0.82	0.70	0.27	0.15
5	3.58	2.73	1.76	0.91	0.19
10	6.79	4.63	3.23	1.55	0.24
20	11.42	8.23	5.67	2.89	0.31
LSD, 5%	0.63	0.27	0.15	0.29	0.01
- - - - - - Lafitte muck (soil No. 12) - - - - - - -					
0	2.96	2.27	1.48	0.17	0.22
5	5.25	3.78	2.50	0.22	0.25
10	6.42	5.12	3.23	0.27	0.28
20	10.09	8.85	5.50	0.39	0.38
LSD, 5%	0.73	0.60	0.35	0.05	0.04

1/ Cu was applied at rates equivalent to 0, 5, 10, and 20 ppm as $CuSO_4 \cdot 5H_2O$, 25% Cu.

Table 20. The percent recovery of applied Cu as an average of four Cu rates by five extractants from Myatt fine sandy loam and Lafitte muck.

Soil	$HCl+$ $AlCl_3$	0.5N HCl	0.1N HCl	DTPA-TEA pH 7.3	NH_4OAc pH 4.8
	- - - - - - - - -	- - -	%	- - - - -	- - - - - - - -
Myatt fine sandy loam	50.3	37.0	25.2	13.1	0.83
Lafitte muck	34.7	32.9	19.9	1.1	0.80

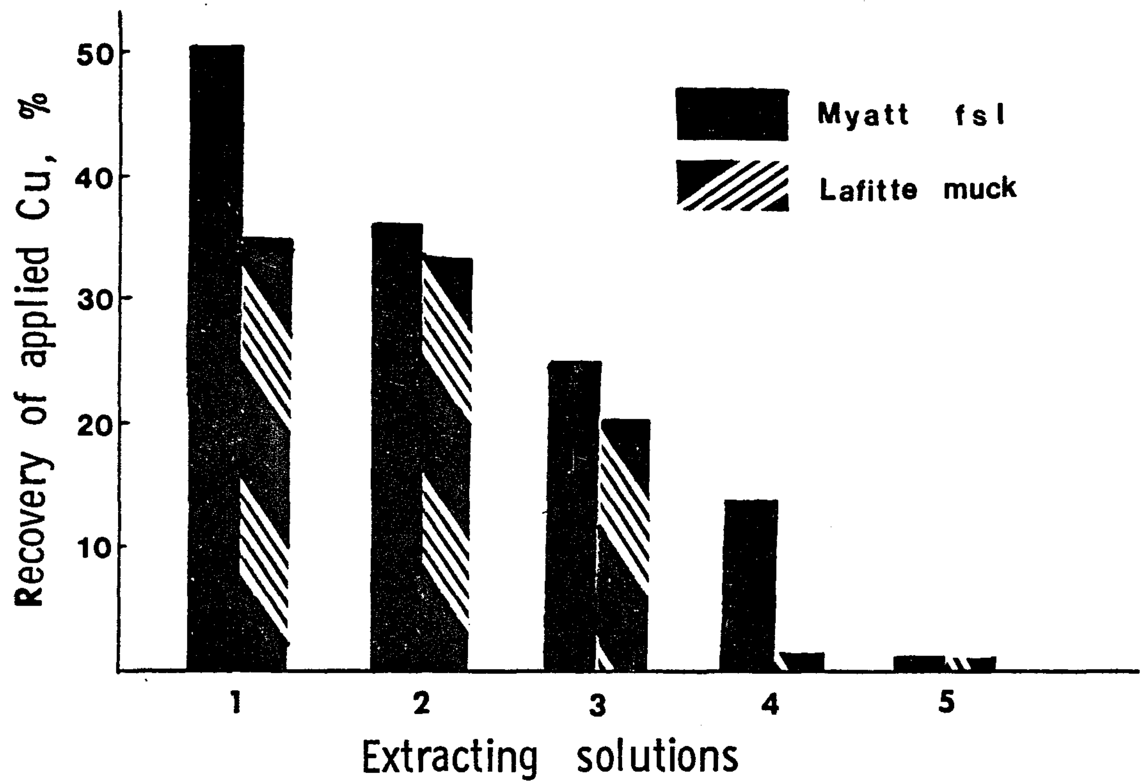

Figure 32. The percent recovery of applied Cu by five extracting solutions.
1) 0.5N HCl+0.05N $AlCl_3$, 2) 0.5N HCl, 3) 0.1N HCl
4) DTPA-TEA, pH 7.3, 5) 1N NH_4OAc, pH 4.8.

Table 21. Relationships as shown by correlation and regression data between Cu extracted from Myatt fine sandy loam and Lafitte muck with five extracting solutions and Cu concentration in plant tissue and Cu uptake by Saturn rice plants.

Cu contents extracted with	Cu concentration	Cu uptake
	- - - - - Myatt fine sandy loam - - - - -	
1. 0.5$\underline{N}$ HCl+0.05$\underline{N}$ $AlCl_3$	$\hat{Y}$ = 4.63+1.64X r = 0.983**	$\hat{Y}$ = 35.83+9.56X r = 0.963**
2. 0.5$\underline{N}$ HCl	$\hat{Y}$ = 4.98+2.24X r = 0.978**	$\hat{Y}$ = 37.87+13.1X r = 0.968**
3. 0.1$\underline{N}$ HCl	$\hat{Y}$ = 4.87+3.28X r = 0.984**	$\hat{Y}$ = 37.13+19.2X r = 0.966**
4. DTPA-TEA, pH 7.3	$\hat{Y}$ = 5.40+6.24X r = 0.980**	$\hat{Y}$ = 40.14+36.6X r = 0.963**
5. 1$\underline{N}$ NH_4OAc, pH 4.8	$\hat{Y}$ =-7.61+97.5X r = 0.975**	$\hat{Y}$ =-36.85+575X r = 0.963**
	- - - - - Lafitte muck - - - - -	
1. 0.5$\underline{N}$ HCl+0.05$\underline{N}$ $AlCl_3$	$\hat{Y}$ = 2.33+1.28X r = 0.969**	$\hat{Y}$ = 13.76+6.92X r = 0.930**
2. 0.5$\underline{N}$ HCl	$\hat{Y}$ = 3.60+1.33X r = 0.951**	$\hat{Y}$ = 21.37+7.02X r = 0.894**
3. 0.1$\underline{N}$ HCl	$\hat{Y}$ = 3.23+2.22X r = 0.957**	$\hat{Y}$ = 18.67+11.9X r = 0.917**
4. DTPA-TEA, pH 7.3	$\hat{Y}$ = 0.55+36.9X r = 0.928**	$\hat{Y}$ = 3.46+201.4X r = 0.903**
5. 1$\underline{N}$ NH_4OAc, pH 4.8	$\hat{Y}$ =-4.07+50.6X r = 0.907**	$\hat{Y}$ =-18.7+265.4X r = 0.848**

** : P < .01.

recovered with all of the extracting solutions from Myatt fine sandy loam than from Lafitte muck. The data suggest that the Lafitte soil had a greater capacity to retain Cu than did the Myatt soil. It has been demonstrated that soils containing relatively large amounts of organic matter have the capacity to retain large amounts of Cu and other heavy metal cations(Mortensen, 1963; Schnitzer and Skinner, 1965; Hodgson, Geering, and Norvell, 1965).

Relationships as shown by correlation and regression analyses between Cu extracted from Myatt fine sandy loam and Lafitte muck with five extracting solutions and Cu concentration in plant tissue and Cu uptake by Saturn rice are presented in Table 21. The data show that levels of Cu extracted with the five extractants from the soils that received an application of Cu were significantly related to levels of Cu in plant tissue and uptake of Cu by rice. The data also show that no one method appeared to be superior to another for extracting Cu on soils that had received an application of Cu.

The influence of flooding, soil reaction(pH), and application of Cu on dry matter production, and total chlorophyll content of the "Y" leaves of Saturn rice grown on Lafitte muck is presented in Table 22 and Figures 33 and 34. The data in Table 22 and Figure 33 show that the production of dry matter by rice was significantly influenced by flooding and soil reaction(pH). The production of dry matter by rice plants on flooded soil was greater than that produced on nonflooded soil. The results are in agreement with those reported by Lin(1946), Clark, Nearpass, and Sprecht(1957), Senewiratne and Mikkelsen (1961), Chaudhry and McLean(1963), Aymond(1972), and Giordano and Mortvedt(1972).

Increasing the soil pH by application of lime resulted in a progressive decrease in the amounts of dry matter produced by the plants. The data show that when the pH of the Lafitte muck was adjusted to 5.9 or higher, the production of dry matter was reduced. The rice plants grew better at lower pH levels than at higher pH levels, irrespective of the flooding treatment.

A significant interaction was found between flooding and soil reaction on the production of dry matter. There was no significant effect of flooding on the amounts of dry matter produced by rice at pH levels ≤ 5.4. However, dry matter production by the plants grown at pH levels $\geq$ 5.9 was significantly influenced by flooding. Under nonflooded conditions, dry matter production decreased sharply with each increase in pH levels. Significantly higher amounts of dry matter were produced by rice plants grown under flooded conditions at pH levels ≥ 5.9.

The data in Table 22 and Figure 33 also show that the

Table 22. The influence of flooding, soil reaction(pH), and application of Cu on dry matter production and total chlorophyll content of the "Y" leaves of Saturn rice plants grown on Lafitte muck.

Treatments		Soil reaction(pH) 4.2	4.8	5.4	5.9	6.3	6.7	Mean	ANOV 2/
		Dry matter production, g/pot							
Flooded	No Cu	3.8	4.0	4.0	3.8	3.7	3.5	3.8	A **
	Cu 1/	4.5	4.6	4.7	4.2	3.7	3.7	4.2	B **
	Mean	4.2	4.3	4.3	4.0	3.7	3.6	4.0	AB**
Nonflooded	No Cu	3.7	3.9	3.4	3.0	2.2	1.8	3.0	C **
	Cu	4.2	4.1	3.9	3.4	2.5	1.8	3.3	ACns
	Mean	4.0	4.0	3.6	3.2	2.3	1.8	3.1	BCns
pH mean		4.1	4.2	4.0	3.6	3.0	2.7	3.6	ABCns
Cu mean		No Cu : 3.4	Cu : 3.8						
		Total chlorophyll content, mg/ 8 "Y" leaves							
Flooded	No Cu	10.64	11.08	11.31	11.39	11.65	10.72	11.30	A *
	Cu	12.84	15.03	14.26	12.95	12.58	11.99	13.27	B **
	Mean	11.73	13.06	13.28	12.17	12.11	11.35	12.29	AB**
Nonflooded	No Cu	11.81	12.24	9.38	10.88	7.11	6.00	9.57	C **
	Cu	14.08	13.04	12.98	11.24	7.27	5.59	10.70	ACns
	Mean	12.94	12.65	11.18	11.07	7.19	5.79	10.13	BC*
pH mean		12.34	12.85	12.23	11.61	9.65	8.57	11.21	ABCns
Cu mean		No Cu : 10.44	Cu : 11.99						

1/ Cu was applied at the rate equivalent to 5 ppm as $CuSO_4 \cdot 5H_2O$, 25% Cu.
2/ A : Flooding; B : soil reaction; C : Cu treatment.
* : $P < .05$; ** : $P < .01$.

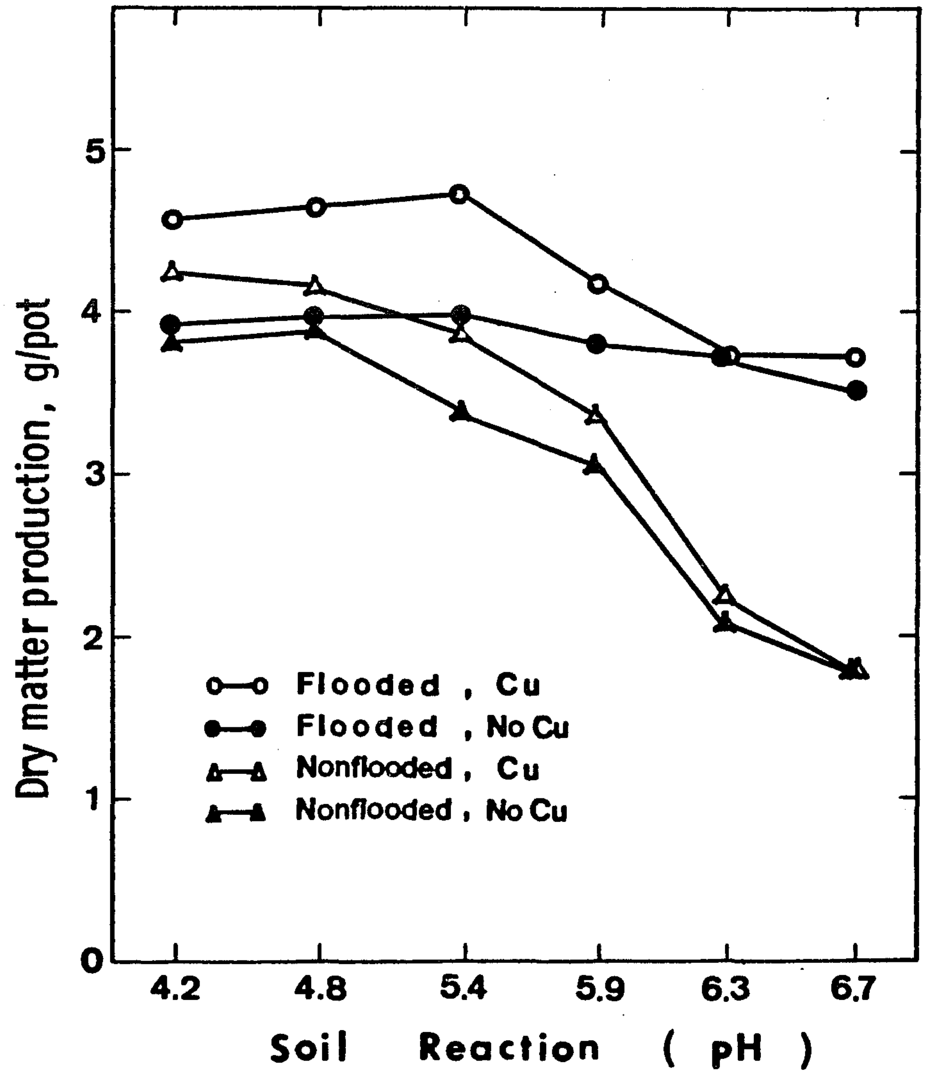

Figure 33. The influence of flooding, soil reaction(pH), and application of Cu on dry matter production by rice plants grown on Lafitte muck.

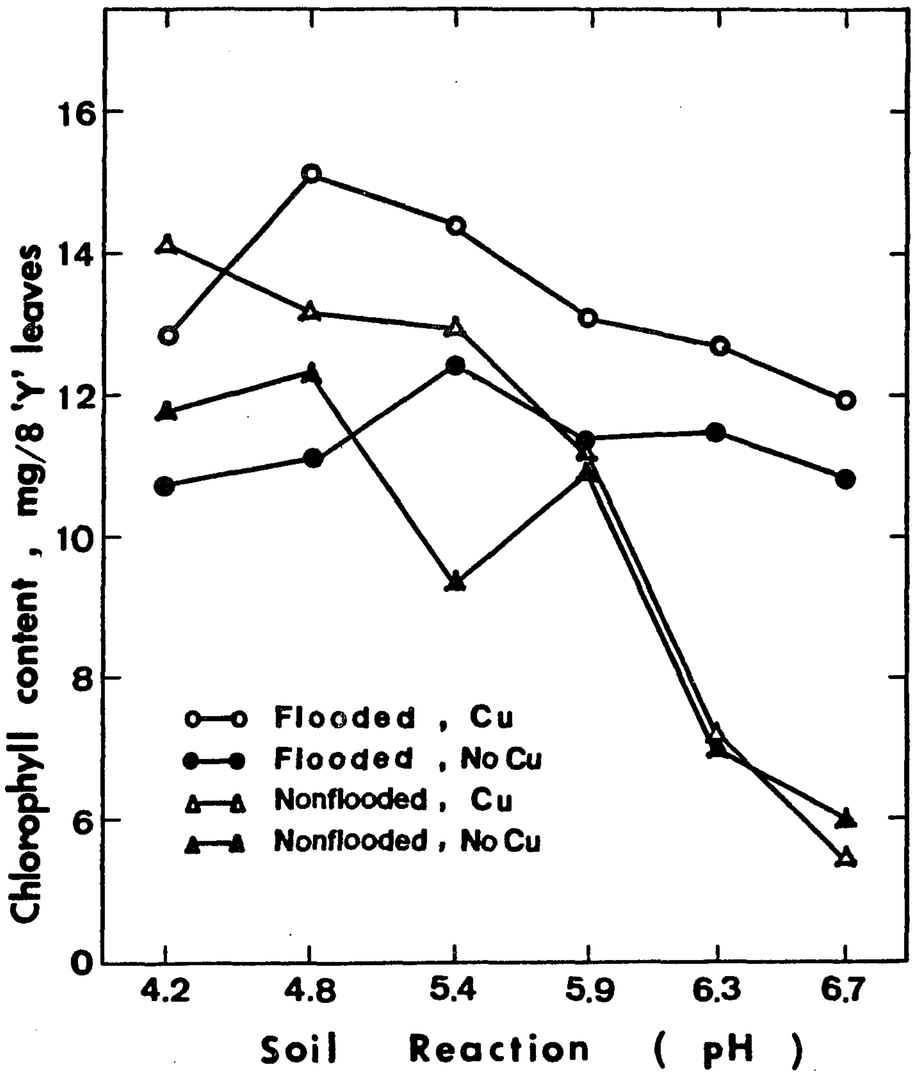

Figure 34. The influence of flooding, soil reaction(pH), and application of Cu on total chlorophyll content of "Y" leaves of rice plants grown on Lafitte muck.

application of 5 ppm of Cu resulted in a significant increase in the production of dry matter by rice plants. Greater responces to applied Cu were obtained at pH levels $\leq$ 5.4 than at the higher pH levels. The results suggest that application of Cu to Lafitte muck be required for better vegetative growth of Saturn rice, even though deficiency symptoms or abnormal growth patterns may not be apparent.

Fretzch(1958) stated that latent Cu deficiencies may be much more important than visual symptoms indicate. Darst and Reeves(1968) stated that the beneficial influences of Cu in plant growth are not due entirely to its essential function as a plant nutrient. They further stated that the second function is not as well defined, it appears that Cu can neutralize harmful conditions which exist in some soils. In this connection, it is thought that Cu can precipitate, or inactivate certain toxic substances present in Cu-deficient organic soils.

As shown in Table 22 and Figure 34, flooding and soil pH, alone and in combination, significantly influenced the total chlorophyll content of "Y" leaves of rice plants at six weeks of age. Total leaf chlorophyll was significantly higher in rice plants grown under flooded conditions than under nonflooded conditions.

Under flooded conditions, significantly higher leaf chlorophyll was observed in plants grown at 4.8 and 5.4 than at pH 4.2 or above 5.9. Under nonflooded conditions, higher contents of leaf chlorophyll were found in rice plants grown at pH 4.2, and decreasing amounts as pH levels were increased. There were no significant differences in total leaf chlorophyll between under flooded and nonflooded conditions at pH levels ≤ 4.8. Howerer, significant differences were observed at the higher pH levels. Severe reductions in leaf chlorophyll contents were observed in plants at pH 6.3 and 6.7 under nonflooded conditions.

The influence of application of Cu on total leaf chlorophyll content was statistically significant. A significantly higher leaf chlorophyll content was found in rice plants with 5ppm of added Cu than without Cu. The results are in agreement with those reported by Rhyu (1977).

A significant interaction between soil pH and Cu on the chlorophyll content of "Y" leaves of rice was obtained. At pH levels ≤ 5.4, the leaf chlorophyll was significantly increased by application of 5 ppm of Cu. However, at pH levels ≥ 5.9, the increase in chlorophyll was not statistically significant.

The influence of flooding, soil reaction(pH), and application of Cu on the concentration and uptake of Cu by Saturn rice plants is presented in Table 23 and Figures 35 and 36. The data show that the concentration of Cu in rice tissue was significantly higher on the flooded than on the nonflooded Lafitte muck.

The pH level had a pronounced effect on the concentration of Cu in rice plants. The concentrations of Cu in rice tissue were significantly higher at soil pH levels of 4.8, 5.4, and 5.9 than they were at pH levels of 4.2, 6.3 and 6.7. The results are in agreement with the results reported by Lutz, Genter, and Hawkins(1972).

The effect of pH levels on the concentration of Cu depended upon flooding. At soil pH levels of 4.8, 5.4 and 5.9, the concentration of Cu in the tissue of rice plants grown on flooded Lafitte muck was significantly higher than on the nonflooded soil. However, at a soil pH of 4.2 and at pH levels of 6.3 and 6.7, the concentration of Cu in rice tissue on flooded soil was significantly lower than under nonflooded conditions.

The data in Table 23 and Figure 35 show that the application of Cu resulted in a significant increase in the concentration of Cu in rice tissue. There were significant interactions between the application of Cu and flooding, and between the application of Cu and levels of soil pH on the concentration of Cu in rice tissue. On the Lafitte soil that did not receive supplementary Cu, rice plants tended

Table 23. The influence of flooding, soil reaction(pH), and application of Cu on the concentration and uptake of Cu by Saturn rice plants grown on Lafitte muck.

Treatments		Soil reaction (pH) 4.2	4.8	5.4	5.9	6.3	6.7	Mean	ANOV[2/]
- - - - -				Cu concentration, ppm					- -
Flooded	No Cu	6.50	9.12	8.50	6.88	5.88	5.88	7.13	A **
	Cu 1/	9.25	15.25	14.87	13.50	8.63	7.75	11.54	B **
	Mean	7.88	12.19	11.69	10.19	7.25	6.81	9.33	AB **
Nonflooded	No Cu	7.00	7.75	7.63	7.63	7.13	6.75	7.31	C **
	Cu	9.75	11.88	11.50	11.00	9.63	9.00	10.46	AC **
	Mean	8.38	9.81	9.56	9.31	8.38	7.88	8.89	BC **
	pH mean	8.13	11.00	10.63	9.75	7.81	7.34	9.11	ABCns
	Cu mean	No Cu : 7.21		Cu : 11.00					
- - - - -				Cu uptake, µg/pot					- -
Flooded	No Cu	25.1	36.0	33.6	26.3	22.2	21.0	27.4	A **
	Cu	41.4	70.5	69.7	57.2	31.9	28.5	49.9	B **
	Mean	33.2	53.2	51.6	41.7	27.0	24.7	38.6	AB **
Nonflooded	No Cu	26.2	30.2	25.7	22.9	15.3	12.0	22.1	C **
	Cu	41.0	49.1	44.3	36.9	23.8	16.0	35.2	AC **
	Mean	33.6	39.7	35.0	29.9	19.6	14.0	28.6	BC **
	pH mean	33.4	46.5	43.3	35.8	23.3	19.4	33.6	ABCns
	Cu mean	No Cu : 24.7		Cu : 42.5					

1/ Cu was applied at the rate equivalent to 5 ppm as $CuSO_4 \cdot 5H_2O$, 25% Cu.
2/ A : Flooding; B : Soil reaction; C : Cu treatments.
* : $P < .05$; ** : $P < .01$.

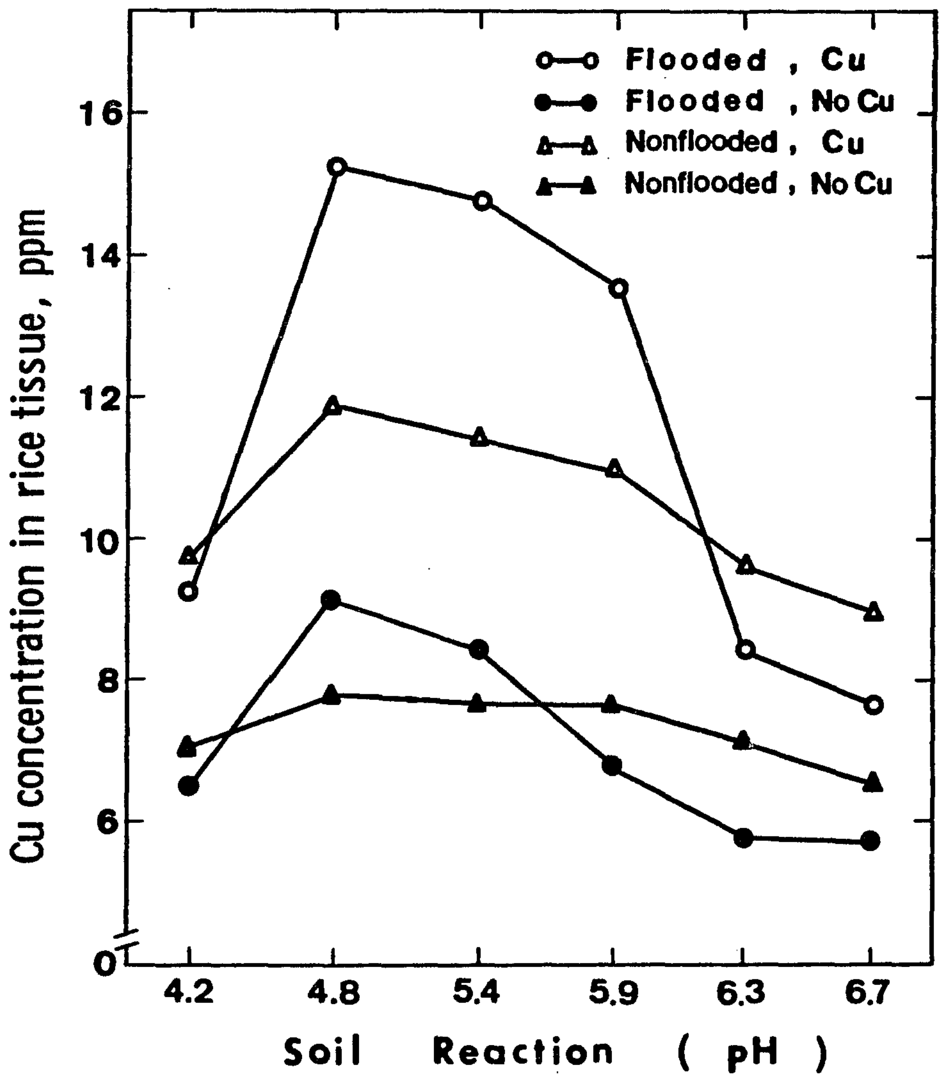

Figure 35. The influence of flooding, soil reaction(pH), and application of Cu on Cu concentration in rice tissue grown on Lafitte muck.

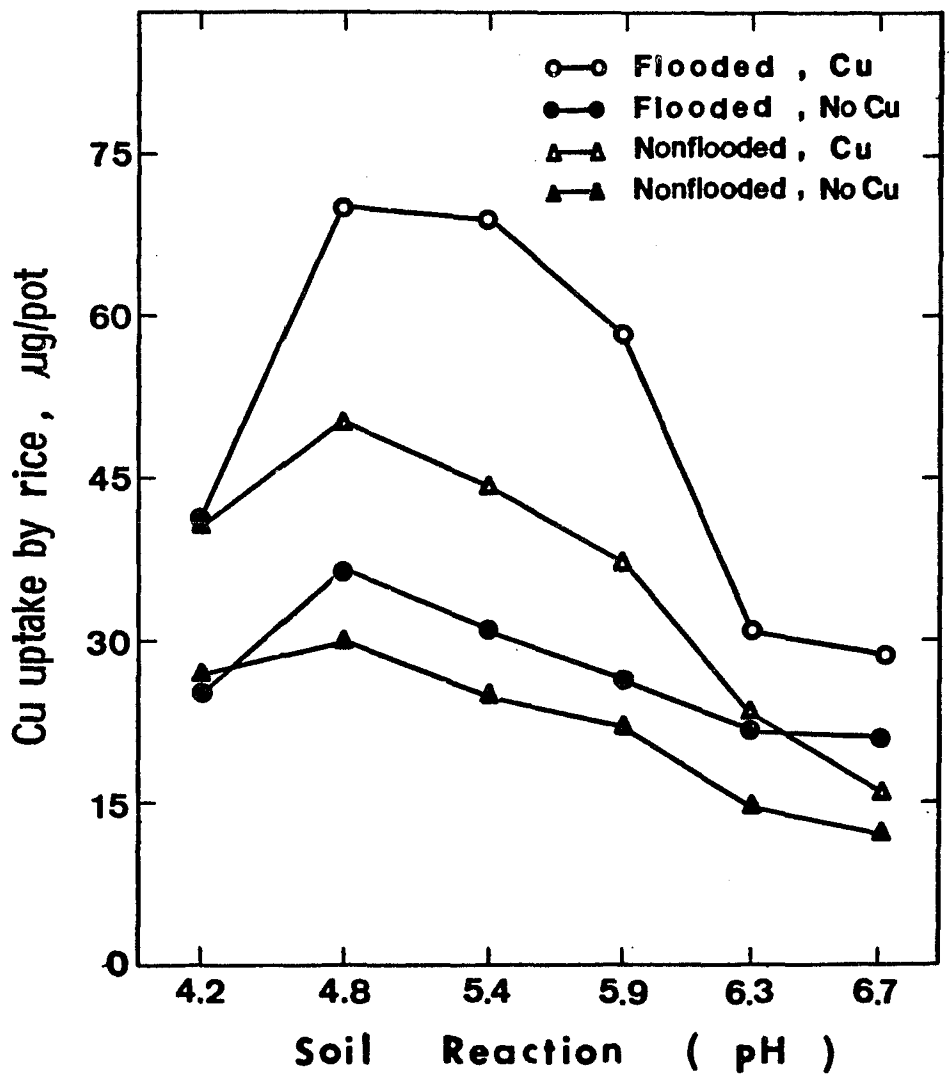

Figure 36. The influence of flooding, soil reaction(pH), and application of Cu on Cu uptake by rice plants grown on Lafitte muck.

to have lower concentration of Cu under flooded conditions than under nonflooded conditions. With the application of Cu, the concentration of Cu in rice plants grown under flooded conditions was significantly higher than under nonflooded conditions.

Without applied Cu, no significant difference in tissue concentration of Cu was observed at any pH level. With applied Cu, significantly higher tissue concentrations of Cu were observed at soil pH levels of 4.8, 5.4, and 5.9.

The data in Table 23 and Figure 36 show that the effects of flooding and pH levels on the uptake of Cu by rice plants grown on the muck soil were similar to those obtained on the Cu concentration in rice tissue. The uptake of Cu by rice plants under flooded conditions was significantly higher than under nonflooded conditions. Significantly greater uptake of Cu by rice plants was observed at pH levels of 4.8 and 5.4 than at pH levels of 4.2 and 5.9. Adjusting the soil reaction to pH 6.3 and 6.7 resulted in a severe reduction in the uptake of Cu by rice plants.

The application of 5 ppm of Cu caused a significant increase in the uptake of Cu by the plants. Significant interactions were obtained between applied Cu and flooding, and between applied Cu and soil pH as influencing the uptake of Cu. High amounts of Cu were taken up by rice plants on flooded soils that received an appleication of 5 ppm of Cu. In general, lower amounts of Cu were taken up by rice plants grown on nonflooded soils that did not receive Cu. The uptake of Cu by rice plants was greater on the nonflooded soil that received an application of Cu than it was on the flooded soil that did not receive Cu.

The influence of flooding, soil reaction(pH), and application of Cu on the concentration and uptake of Zn by rice plants grown on Lafitte muck is presented in Table 24 and in Figures 37 and 38. The data show that the concentration of Zn in rice tissue was dependent upon the flooding treatments and soil pH levels. No significant interaction was found between flooding and soil reaction on the concentration of Zn in rice tissue. Significantly higher tissue concentration of Zn was found on nonflooded soils than on flooded soils. The results agree with those reported by IRRI(1970), Hem(1972), Kittrick(1976), but disagree with the results obtained by Bingham, et al. (1976).

Zn concentrations in rice plants decreased progressively by increasing the soil reaction from pH 4.8 to 6.7. A significantly higher concentration of Zn in plant tissue was found at pH 4.8 than at pH 4.2. It has been well established that the increase in pH following application of limestone reduces the availability of Zn in

Table 24. The influence of flooding, soil reaction(pH), and application of Cu on the concentration and uptake of Zn by Saturn rice plants grown on Lafitte muck.

Treatments		Soil reaction (pH) 4.2	4.8	5.4	5.9	6.3	6.7	Mean	ANOV 2/
		Zn concentration, ppm							
Flooded	No Cu	51.8	66.1	61.3	52.6	44.9	39.1	52.6	A **
	Cu 1/	52.5	71.1	63.6	55.4	40.0	36.2	53.1	B **
	Mean	52.1	68.6	62.4	54.0	42.4	37.7	52.8	AB ns
Nonflooded	No Cu	57.1	73.0	64.0	58.9	50.5	48.5	58.7	C ns
	Cu	59.9	77.4	70.6	56.5	47.9	47.1	59.9	AC ns
	Mean	58.5	75.2	67.3	57.7	49.2	47.8	59.3	BC **
pH mean		55.3	71.9	64.9	55.8	45.8	42.8	56.1	ABCns
Cu mean		No Cu : 55.6		Cu : 56.5					
		Zn uptake, μg/pot							
Flooded	No Cu	199	262	242	201	169	137	202	A **
	Cu	235	329	297	234	147	133	229	B **
	Mean	217	296	269	218	158	135	216	AB **
Nonflooded	No Cu	214	285	217	177	109	86	181	C *
	Cu	252	319	272	189	118	84	206	AC ns
	Mean	233	302	245	183	114	85	193	BC **
pH mean		225	299	257	200	136	110	205	ABCns
Cu mean		No Cu : 192		Cu : 217					

1/ Cu was applied at the rate equivalent to 5 ppm as $CuSO_4 \cdot 5H_2O$, 25% Cu.
2/ A : Flooding; B : Soil reaction; C : Cu treatments.
* : $P < .05$; ** : $P < .01$.

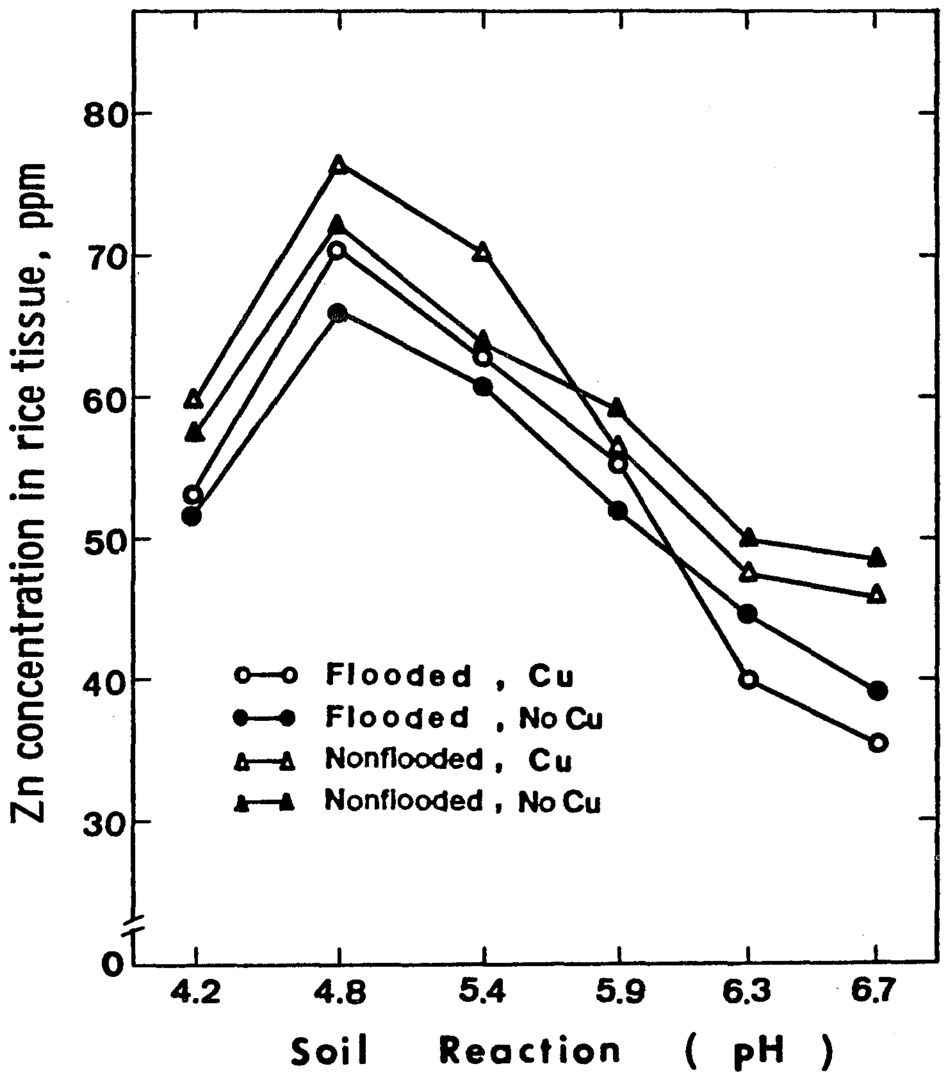

Figure 37. The influence of flooding, soil reaction(pH), and application of Cu on Zn concentration in rice tissue grown on Lafitte muck.

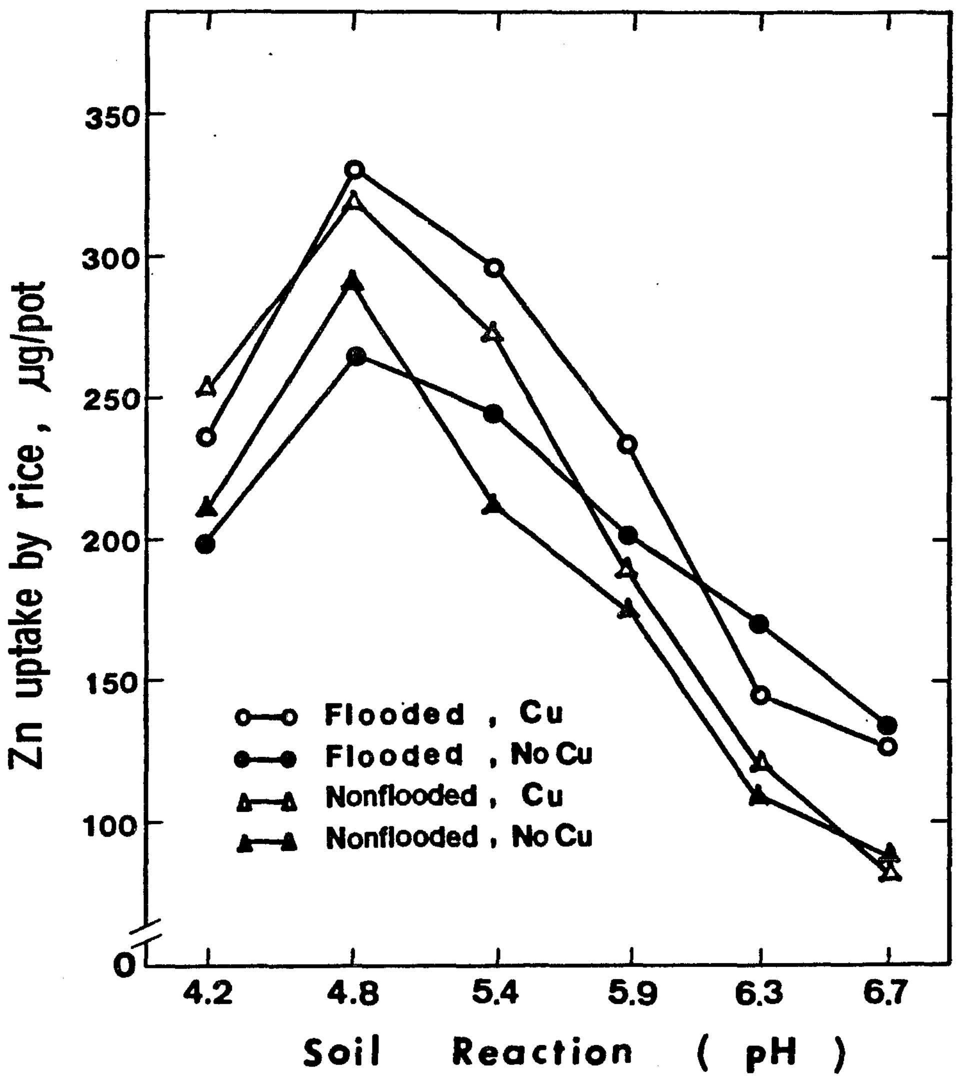

Figure 38. The influence of flooding, soil reaction(pH), and application of Cu on Zn uptake by rice plants grown on Lafitte muck.

soil and the concentration of Zn in plant tissue(Roger and Chik-Hwa-Wu, 1948; Wear, 1956; Seatz, Sterges, and Kramer, 1959; Brown and Jurinak, 1964; Kahn, 1969; Aymond, 1972; Sedberry, et al., 1980).

The application of Cu alone or in combination with flooding did not significantly influence the concentration of Zn in rice tissue. A highly significant interaction was found between application of Cu and soil reaction on the concentration of Zn in rice tissue. The application of Cu resulted in a significant increase in the concentration of Zn in rice tissue when the soil reaction was $\leq$pH 5.4. The application of Cu resulted in a significant decrease in the concentration of Zn at pH 6.3 and 6.7. No explanation can be offered as to why the application of Cu resulted in a significant increase in Zn concentration in plant tissue at the lower pH levels and a decrease in Zn at the higher pH levels.

The influence of flooding, soil reaction(pH), and application of Cu on the uptake of Zn by rice plants grown on Lafitte muck is presented in Table 24 and Figure 38. The uptake of Zn by rice plants was significantly greater under flooded conditions than under nonflooded conditions. The results are in agreement with the results obtained by Giordano and Mortvedt(1972), and disagree with the results reported at IRRI(1970).

Large amounts of Zn were taken up by rice plants at soil pH 4.8, followed by 5.4 and 4.2. Increasing the soil reaction from pH 5.9 to 6.3 and 6.7 resulted in a 32% and 45% reduction in the uptake of Zn respectively. A significant interaction between flooding treatments and soil pH levels was found for the uptake of Zn by rice plants. At pH 4.2 and 4.8, the uptake of Zn by rice was higher under nonflooded conditions than under flooded conditions; the opposite results were obtained at higher soil pH levels.

The data in Table 24 and Figure 38 show that the application of Cu resulted in a significant increase in the uptake of Zn by rice. However, the influence of application of Cu on the uptake of Zn by rice significantly depended upon soil pH. The application of Cu resulted in a significant increase in the uptake of Zn by rice plants at pH levels $\leq$ 5.4, but at pH 6.3 and 6.7, the application of Cu did not significantly influence the uptake of Zn.

The lower concentration of Zn in rice tissue grown under flooded conditions or at higher pH levels as compared to those under nonflooded conditions or at lower pH levels may be due partly to a reduction in the solubility and availability of Zn by precipitation as ZnS under reduced conditions(Kittrick, 1976), by precipitation of $ZnCO_3$ due to CO_2 accumulation resulting from organic matter decomposition(Hem, 1972), or by the formation of negatively charged zincate complexes at higher pH levels(Camp, 1945). It has been demonstrated that the addition of $CaCO_3$ to the soil induced Zn deficiency in rice plants(Kahn, 1969; Sedberry, et al., 1980).

The influence of flooding, soil reaction(pH), and application of Cu on the concentration and uptake of Mn by rice plants grown on Lafitte muck is presented in Table 25 and Figures 39 and 40. The data in Table 25 and Figure 39 show that flooding the Lafitte soil significantly influenced the concentration of Mn in rice tissue. The concentration of Mn in rice plants under flooded conditions was significantly lower than those under nonflooded conditions. The results are in agreement with those reported by Senewiratne and Mikkelsen(1961), but contradict the research conducted by Clark, Nearpass, and Sprecht (1957), Aymond(1972), and Bingham, et al.(1976).

The pH levels and flooding treatments together significantly influenced the concentration of Mn in rice plants. Under both flooded and nonflooded conditions, The highest concentration of Mn in rice was found in the plants grown at pH 4.8. The concentration of Mn in rice decreased progressively with an increase in soil reaction from pH 4.8 to 6.7. This finding is in agreement with report of Gupta, Chipman, and MacKay(1970). They reported that on acid sphagnum peat soil, the highest content of Mn in carrot

Table 25. The influence of flooding, soil reaction(pH), and application of Cu on the concentration and uptake of Mn by Saturn rice plants grown on Lafitte muck.

Treatments		Soil reaction (pH) 4.2	4.8	5.4	5.9	6.3	6.7	Mean	ANOV 2/
- - - - - - - - Mn concentration, ppm - - - - - - -									
Flooded	No Cu	854	1,675	1,243	701	541	401	903	A **
	Cu 1/	836	1,648	1,126	764	565	391	888	
	Mean	845	1,661	1,184	733	553	398	896	B **
Nonflooded	No Cu	1,394	2,440	1,446	724	673	814	1,248	AB **
	Cu	1,380	2,664	1,431	831	874	893	1,346	C ns
	Mean	1,387	2,552	1,496	778	773	854	1,296	AC ns
pH mean		1,116	2,107	1,312	755	663	626	1,096	BC ns
Cu mean		No Cu : 1,076		Cu : 1,117					ABCns
- - - - - - - - Mn uptake, mg/pot - - - - - - -									
Flooded	No Cu	3.29	6.61	4.91	2.68	2.07	1.45	3.50	A **
	Cu	3.74	10.98	6.27	3.22	2.10	1.42	4.46	
	Mean	3.51	8.80	5.09	2.95	2.08	1.43	3.98	B **
Nonflooded	No Cu	5.20	9.48	4.88	2.16	1.47	1.43	4.10	AB **
	Cu	5.80	9.77	5.51	2.79	2.15	1.58	4.60	C *
	Mean	5.50	9.62	5.19	2.48	1.81	1.50	4.35	AC ns
pH mean		4.51	9.21	5.14	2.71	1.94	1.47	4.16	BC **
Cu mean		No Cu : 3.80		Cu : 4.53					ABC**

1/ Cu was applied at the rate equivalent to 5 ppm as $CuSO_4 \cdot 5H_2O$, 25% Cu.
2/ A : Flooding; B : Soil reaction; C : Cu treatments.
* : $P < .05$; ** : $P < .01$.

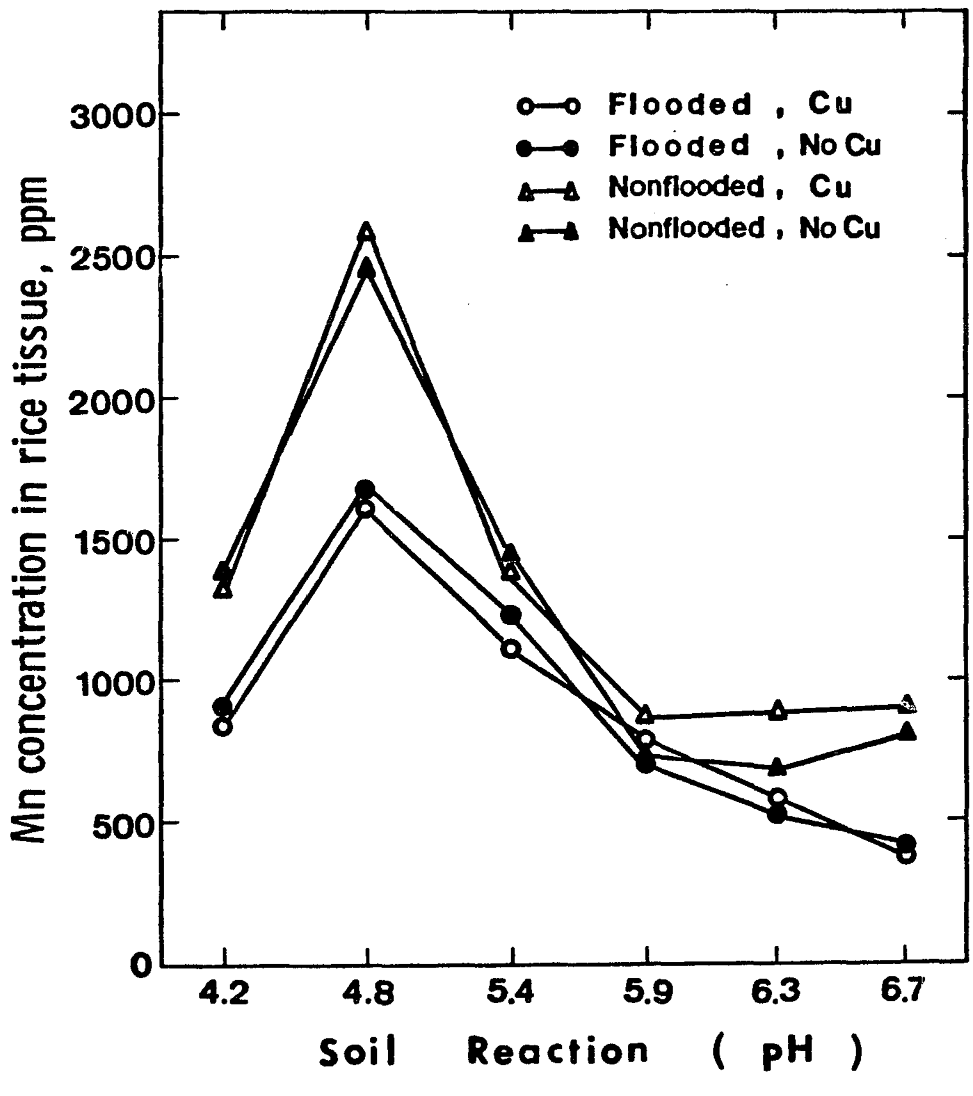

Figure 39. The influence of flooding, soil reaction(pH), and application of Cu on Mn concentration in rice tissue grown on Lafitte muck.

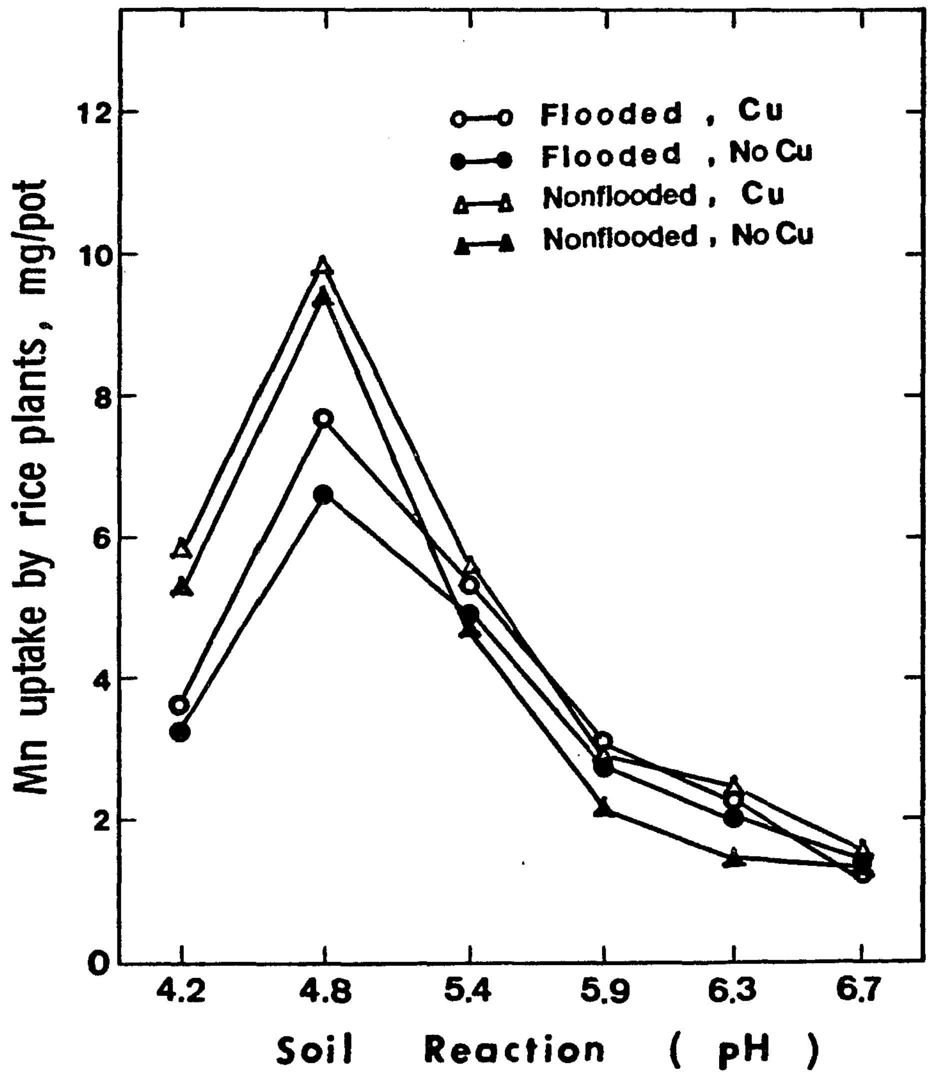

Figure 40. The influence of flooding, soil reaction(pH), and application of Cu on Mn uptake by rice plants grown on Lafitte muck.

tissue occurred at pH values of 4.4 to 5.6, and the lowest at pH 6.2 and 6.4. They further reported that the Mn concentration was higher at pH 4.4 or 5.1 than at pH 4.1.

A significant interaction between flooding and soil pH on the concentration of Mn in rice plants was obtained. Under flooded conditions, the concentration of Mn in rice tissue decreased progressively as pH levels increased from 4.8 to 6.7. Under nonflooded conditions, the concentration of Mn in rice tissue did not decrease as soil reaction was increased above pH 5.9. The concentration of Mn in plant tissue was slightly higher at pH 6.7 than it was at pH 5.9.

The application of Cu did not significantly influence the average concentration of Mn in the plants. The results are in agreement with those reported by Ohki(1975). Significant interactions between flooding and applied Cu, and between soil reaction and applied Cu were not found.

The data presented in Table 25 and Figure 40 show that the uptake of Mn by rice plants grown on Lafitte muck depended on flooding and pH levels. The uptake of Mn by rice under nonflooded conditions was significantly higher than under flooded conditions. The highest uptake of Mn was found at pH 4.8. The Mn uptake at pH 4.8 was approximately 2, 3.5, or 6 times higher than that at pH 4.2 and

5.4, 5.9, or at pH 6.7, respectively.

The data show that a significant interaction between flooding and soil reaction occurred and this apparently influenced the uptake of Mn by rice plants. At soil pH levels ≤ 5.4 and at pH 6.7, the uptake of Mn tended to be higher under nonflooded conditions than under flooded conditions. At pH 5.9 and 6.3, the Mn uptake under flooded conditions tended to be higher than under non-flooded conditions. Significantly higher amounts of Mn were taken up by rice plants at pH 4.2 under nonflooded conditions than under flooded conditions.

The uptake of Mn by rice plants was significantly higher with applied Cu than without it. Highly significant interactions were obtained between soil reaction and Cu, and among the flooding-pH-Cu treatments.

The influence of flooding, soil reaction(pH), and application of Cu on the concentration of Fe by rice plants grown on Lafitte muck is presented in Table 26 and Figures 41 and 42. The data show that significantly higher concentration of Fe in rice tissue occurred on flooded soil than on nonflooded soil. The results are in agreement with those reported by Senewiratne and Mikkelsen(1961), Chaudhry and McLean(1963), Ponnamperuma(1965), and Aymond(1972). Evidently the continuous flooding resulted in reducing conditions favorable for the formation of

Table 26. The influence of flooding, soil reaction(pH), and application of Cu on the concentration and uptake of Fe by Saturn rice plants grown on Lafitte muck.

Treatments		Soil reaction (pH) 4.2	4.8	5.4	5.9	6.3	6.7	Mean	ANOV 2/
		- - - - - - - Fe concentration, ppm - - - - - - -							
Flooded	No Cu	97.1	109.1	111.0	96.1	91.6	86.1	98.5	A **
	Cu 1/	100.6	110.4	113.5	105.1	101.3	99.3	105.0	B **
	Mean	98.9	109.8	112.3	100.6	96.4	92.7	101.8	AB **
Nonflooded	No Cu	91.8	90.5	85.9	78.1	73.9	64.7	80.8	C **
	Cu	101.6	99.0	93.0	89.3	67.1	57.5	84.6	AC ns
	Mean	96.7	94.8	89.4	83.7	70.5	61.1	82.7	BC ns
pH mean		97.8	102.3	100.8	92.2	83.5	76.9	92.2	ABC*
Cu mean		No Cu : 89.7		Cu : 94.8					
		- - - - - - - - Fe uptake, µg/pot - - - - - - - -							
Flooded	No Cu	374	435	441	368	341	304	377	A **
	Cu	450	511	530	440	373	365	445	B **
	Mean	412	473	486	404	357	334	411	AB **
Nonflooded	No Cu	345	350	289	234	156	117	249	C **
	Cu	463	409	358	298	164	102	299	AC ns
	Mean	404	380	323	266	160	109	274	BC ns
pH mean		408	426	404	335	259	222	342	ABCns
Cu mean		No Cu : 313		Cu : 372					

1/ Cu was applied at the rate equivalent to 5 ppm as $CuSO_4 \cdot 5H_2O$, 25% Cu.
2/ A : Flooding; B : Soil reaction; C : Cu treatments.
* : P < .05; ** : P < .01.

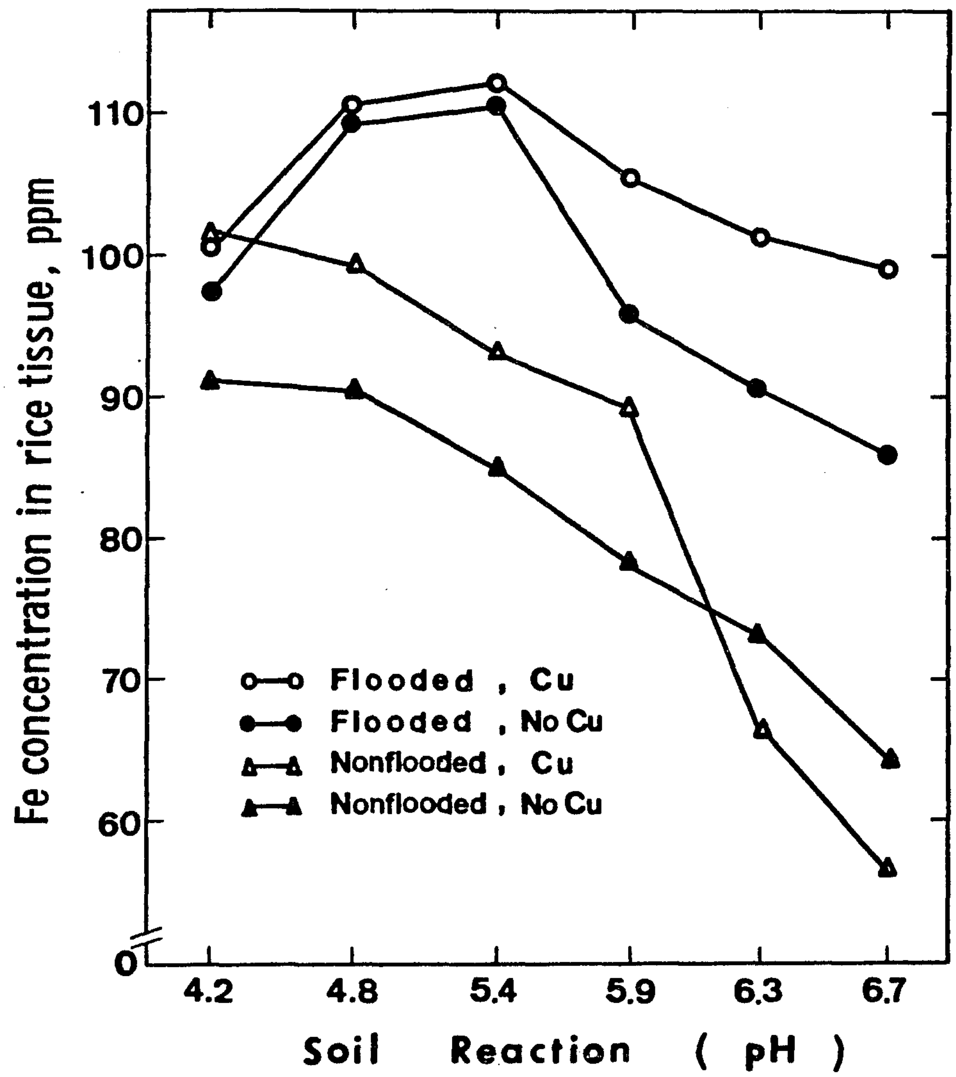

Figure 41. The influence of flooding, soil reaction(pH), and application of Cu on Fe concentration in rice tissue grown on Lafitte muck.

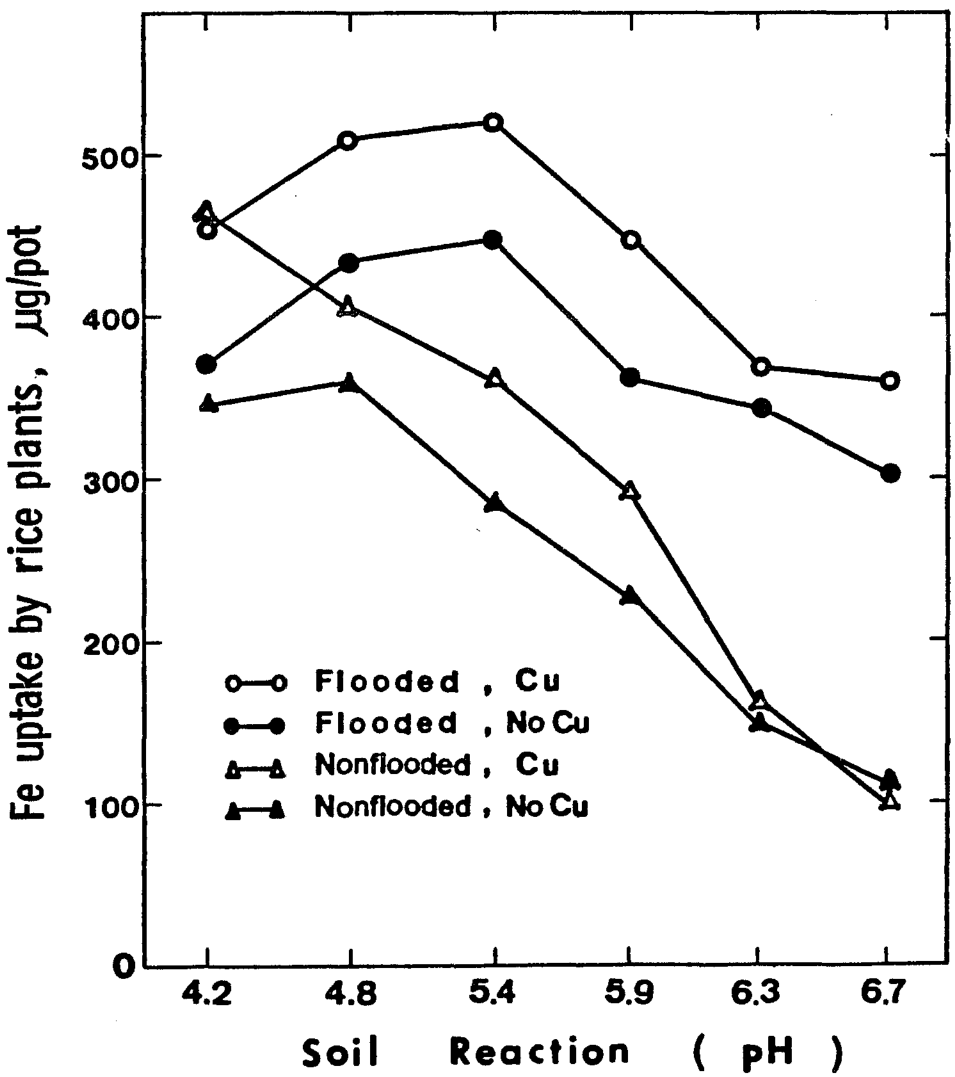

Figure 42. The influence of flooding, soil reaction(pH), and application of Cu on Fe uptake by rice plants grown on Lafitte muck.

Fe^{2+}, which is more available to the plants than oxides of Fe.

The data also show that soil pH levels significantly influenced the concentration of Fe in rice plants. Significantly higher concentrations of Fe were observed in the plants grown at pH levels ≤ 5.4 than those at pH levels ≥ 5.9. There was a significant interaction between flooding and soil reaction, and this apparently influenced the concentration of Fe in rice tissue. Significant differences in plant-tissue Fe were not observed between flooding treatments at pH 4.2. At pH levels ≥ 4.8, significantly higher concentration of Fe in rice tissue was observed under flooded conditions. Increasing soil pH levels resulted in severe reductions in the concentration of Fe in rice plants under nonflooded conditions.

Gotoh and Patrick(1974) reported that at pH 5.0, appreciable reduction of Fe occurred at +300 mv redox potential, while the critical redox potentials for Fe reduction and consequent dissolution occurred between +300 and +100 mv at pH 6.0 and 7.0, and -100 mv at pH 8.0. They also reported that at pH 5.0, water-soluble Fe accounted for 76% of the water-soluble and exchangeable fraction at Eh -250 mv. At pH 8.0, the corresponding value was only 4% at Eh -200 mv. The observed results suggest that redox potentials at all pH levels under flooded conditions were low enough to reduce large amounts of ferric Fe to ferrous Fe. The redox potentials under nonflooded conditions at higher pH levels were not low enough to affect the reduction of Fe.

The application of Cu significantly increased the concentration of Fe in rice plant tissue. The obtained effects of Cu on the concentration of Fe agree with those reported by Dokiya, Owa, and Mitsui(1968).

Nonsignificant interactions were found between flooding and Cu, and between soil pH and Cu on the concentration of Fe in rice tissue. A significant interaction was observed for the flooding-pH-Cu treatments. Under flooded conditions, the application of Cu did not significantly increase the Fe concentration at pH levels ≤ 5.4, but applied Cu significantly increased the concentration of Fe in the plants at pH levels ≥ 5.9. Under nonflooded conditions, the application of Cu resulted in a significant increase in the concentration of Fe in rice tissue at pH levels ≤ 5.9. In contrast, the application of Cu resulted in significant decrease in the concentration of Fe at pH levels ≥ 6.3.

The data in Table 26 and Figure 42 show that the uptake of Fe by rice under flooded conditions was significantly higher than that under nonflooded conditions.

Higher amounts of Fe were taken up by rice at pH levels ≤ 5.4 than those at pH levels ≥ 5.9.

The application of Cu resulted in a significant increase in the uptake of Fe by rice plants. Significant interactions were not found between flooding and Cu, between soil pH and Cu, and among flooding-pH-Cu treatments.

The influence of flooding, soil reaction(pH), and application of Cu on the concentration and uptake of P by rice plants grown on Lafitte muck is presented in Table 27 and Figures 43 and 44. The data show that the concentration and uptake of P by rice were dependent on flooding, soil pH levels, and interaction of flooding and soil reaction. The concentrations and uptake of P by rice grown under flooded conditions were significantly higher than they were under nonflooded conditions. Substantial increase in the availability of both native and applied P in flooded soils compared to well drained soils has been reported by Aoki, 1941; Mitsui, 1954; Shapiro, 1958[a], 1958[b]; Redman and Patrick, 1965; Aymond, 1972; Giordano and Mortvedt, 1972; Khalid, Patrick, and DeLaune, 1977.

Patrick and Reddy(1977) stated that P is not directly involved in oxidation-reduction in submerged soils. But, because it reacts with a number of redox elements, its behavior is significantly affected by flooding.

Table 27. The influence of flooding, soil reaction(pH), and application of Cu on the concentration and uptake of P by Saturn rice plants grown on Lafitte muck.

Treatments		Soil reaction (pH)							ANOV2/
		4.2	4.8	5.4	5.9	6.3	6.7	Mean	
- - - - - - - - P concentration, ppm - - - - - - -									
Flooded	No Cu	2,370	2,159	1,895	1,871	1,778	1,712	1,964	A **
	Cu 1/	2,259	1,956	1,826	1,778	1,678	1,604	1,850	B **
	Mean	2,315	2,057	1,860	1,824	1,728	1,658	1,907	AB **
Nonflooded	No Cu	2,030	1,882	1,789	1,586	1,519	1,230	1,672	C **
	Cu	2,011	1,826	1,685	1,574	1,401	1,111	1,601	AC ns
	Mean	2,020	1,854	1,737	1,580	1,460	1,171	1,631	BC ns
pH mean		2,167	1,956	1,799	1,705	1,594	1,414	1,774	ABCns
Cu mean		No Cu : 1,818		Cu : 1,726					
- - - - - - - - P uptake, mg/pot - - - - - - - -									
Flooded	No Cu	9.12	8.61	7.51	7.16	6.66	6.00	7.51	A **
	Cu	10.12	8.92	8.54	7.49	6.16	5.88	7.85	B **
	Mean	9.62	8.76	8.03	7.32	6.41	5.94	7.68	AB **
Nonflooded	No Cu	7.60	7.32	6.04	4.74	3.25	2.16	5.19	C **
	Cu	8.45	7.51	6.47	5.26	3.43	1.97	5.52	AC ns
	Mean	8.03	7.42	6.26	5.00	3.34	2.07	5.35	BC ns
pH mean		8.82	8.09	7.14	6.16	4.88	4.00	6.52	ABCns
Cu mean		No Cu : 6.35		Cu : 6.68					

1/ Cu was applied at the rate equivalent to 5 ppm as $CuSO_4 \cdot 5H_2O$, 25% Cu.
2/ A : Flooding; B : Soil reaction; C : Cu treatments.
** : P < .01.

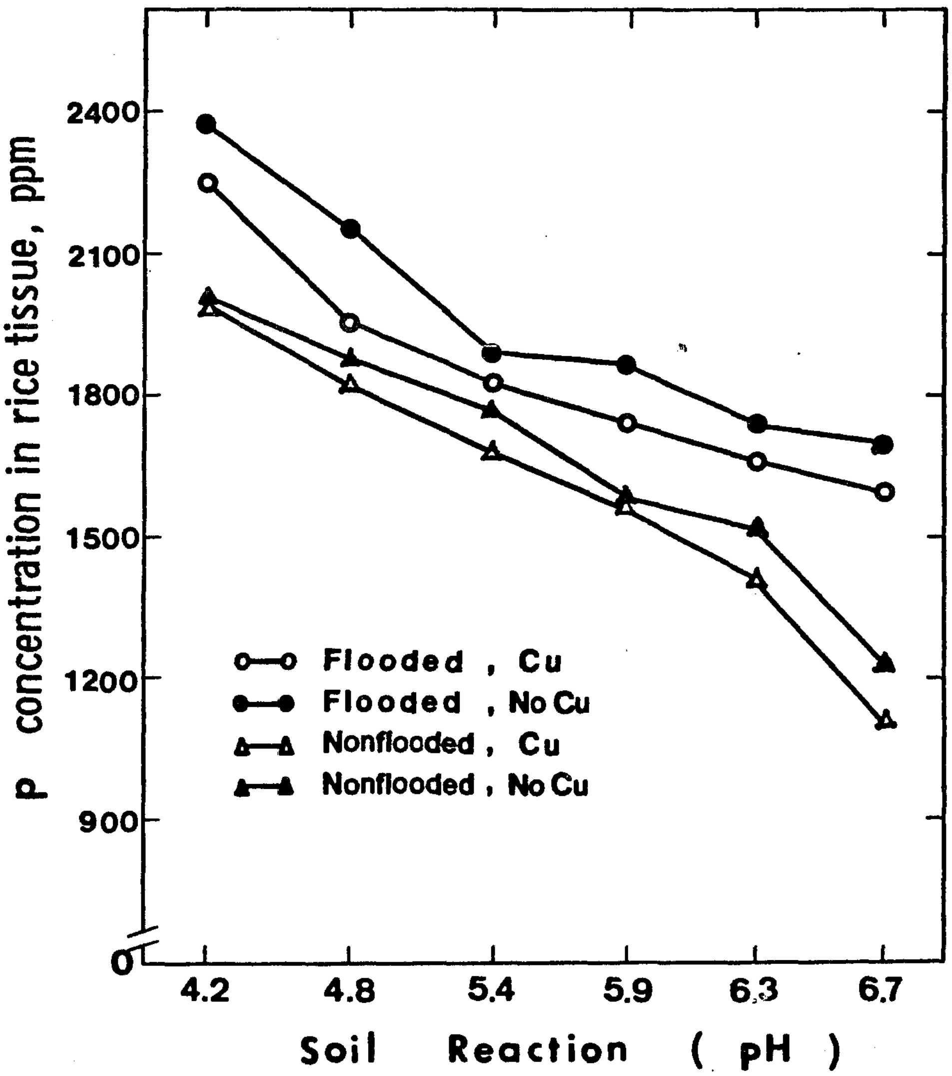

Figure 43. The influence of flooding, soil reaction(pH), and application of Cu on P concentration in rice tissue grown on Lafitte muck.

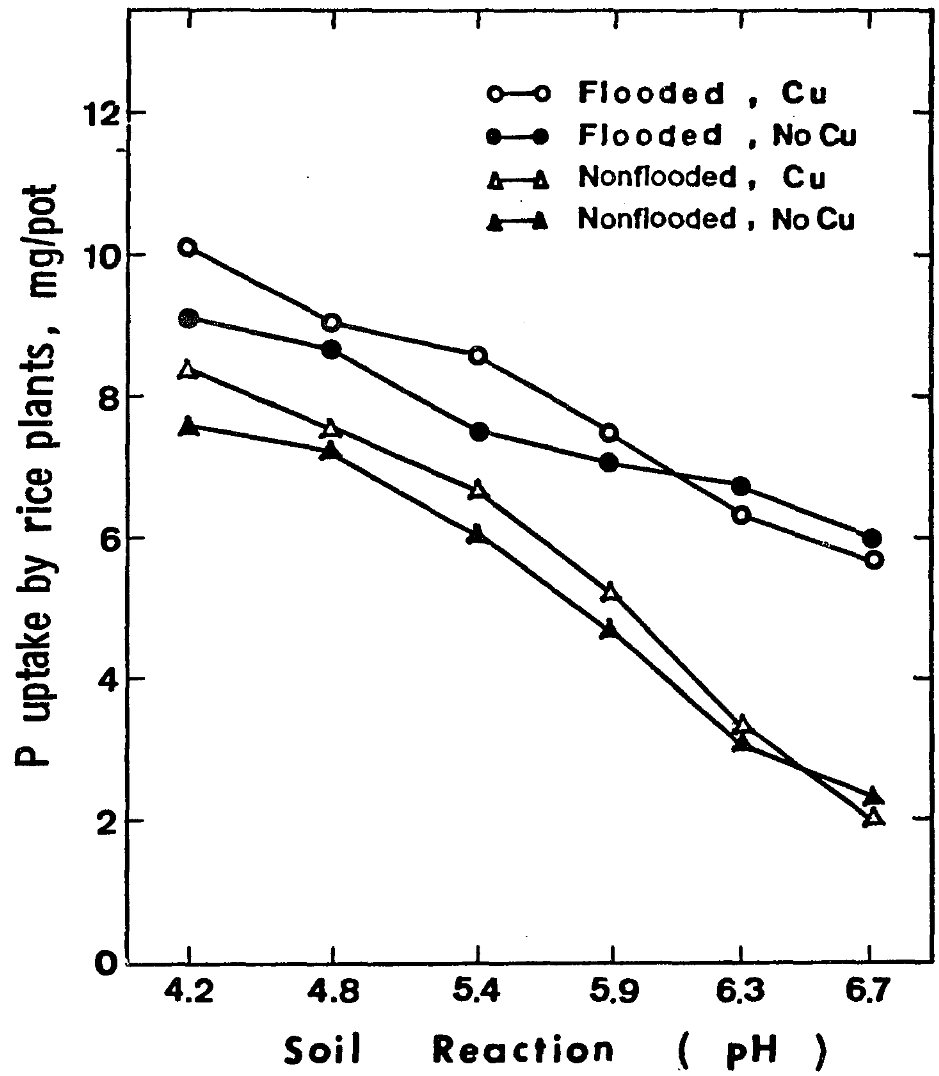

Figure 44. The influence of flooding, soil reaction(pH), and application of Cu on P uptake by rice plants grown on Lafitte muck.

According to the review of literature by Jugsujina (1975), the increase in soluble P upon flooding has been attributed to: (a) displacement of P from insoluble ferric and aluminum P by organic anions(Bradley and Sieling, 1953), (b) the reduction of insoluble ferric phosphate(Islam and Elahi, 1954; Patrick, 1964), (c) hydrolysis of ferric and aluminum phosphates in alkaline soils (Ponnamperuma, 1955; Valencia, 1962), (d) exchange of phosphate adsorbed on clay surfaces by organic anions (Russell, 1961), and (e) release of occluded phosphate (Chang and Jackson, 1958; Redman and Patrick, 1965; and Mahapatra, 1966).

The highest concentration and uptake of P by rice plants on Lafitte muck were found at pH 4.2, and decreased with corresponding increases in soil pH. Increasing levels of soil pH of the nonflooded soil had a more pronounced effect on reducing the concentration and uptake of P than it did on the flooded soils.

The data also show that the concentration of P in rice tissue was significantly decreased by the application of Cu. Cu and P antagonism has been reported by several researchers(Reuther and Smith, 1954; Bingham and Garber, 1960; Locascio, Everett, and Fiskell, 1968; Spencer, 1966; Hulagur, Dangarwala, and Mehta, 1975; Safaya, 1976; and Brown and Jones, 1977).

The influence of flooding, soil reaction(pH), and application of Cu on the concentration and uptake of Ca by rice plants grown on Lafitte muck is presented in Table 28. The concentration of Ca was significantly lower in the plants grown under flooded conditions than under nonflooded conditions, but uptake of Ca by rice was higher under flooded conditions. The greater uptake of Ca could be attributed to the increase in dry matter production by the plants under flooded conditions. The decrease noted in the concentration of Ca in rice tissue under flooded conditions does not agree with the results reported by Aymond (1972). He reported that in Patoutville silt loam, the concentration of Ca in rice tissue under flooded conditions was greater than under nonflooded conditions.

The concentration of Ca in the tissue of rice plants grown on Lafitte muck at pH 4.8 was significantly higher than at pH 4.2. However, a further increase in soil reaction did not significantly increase the concentration of Ca in rice tissue.

Adjustment of the soil reaction to pH 4.8, 5.4, and 5.9 resulted in a significant increase in the uptake of Ca by rice plants. A significant interaction between flooding and pH levels was found on the uptake of Ca by rice plants. Differences in the amounts of Ca taken up by the plants were not as great under flooded conditions as they were

Table 28. The influence of flooding, soil reaction(pH), and application of Cu on the concentration and uptake of Ca by Saturn rice plants grown on Lafitte muck.

Treatments		Soil reaction (pH) 4.2	4.8	5.4	5.9	6.3	6.7	Mean	ANOV 2/
- - - - - - - -				Ca concentration, %	- - - - - - -				
Flooded	No Cu	0.23	0.32	0.33	0.33	0.33	0.32	0.31	A **
	Cu 1/	0.23	0.33	0.34	0.37	0.35	0.33	0.32	B **
	Mean	0.23	0.33	0.33	0.35	0.34	0.33	0.32	AB ns
Nonflooded	No Cu	0.28	0.35	0.37	0.37	0.36	0.38	0.35	C **
	Cu	0.26	0.38	0.39	0.39	0.37	0.42	0.37	AC ns
	Mean	0.27	0.36	0.38	0.38	0.36	0.40	0.36	BC ns
pH mean		0.25	0.35	0.36	0.37	0.35	0.36	0.34	ABCns
Cu mean		No Cu : 0.33		Cu : 0.35					
- - - - - - - -				Ca uptake, mg/pot	- - - - - - - -				
Flooded	No Cu	8.86	12.84	13.07	12.70	12.47	11.34	11.88	A *
	Cu	10.13	15.34	15.78	15.52	12.75	12.24	13.63	B **
	Mean	9.49	14.09	14.42	14.11	12.60	11.79	12.75	AB **
Nonflooded	No Cu	10.34	13.57	12.63	10.95	7.66	6.74	10.32	C **
	Cu	10.82	15.70	14.90	13.16	8.91	7.43	11.82	AC ns
	Mean	10.58	14.63	13.77	12.05	8.29	7.08	11.07	BC ns
pH mean		10.04	14.36	14.09	13.08	10.45	9.44	11.91	ABCns
Cu mean		No Cu : 11.10		Cu : 12.72					

1/ Cu was applied at the rate equivalent to 5 ppm as $CuSO_4 \cdot 5H_2O$, 25% Cu.
2/ A : Flooding; B : Soil reaction; C : Cu treatments.
* : $P < .05$ ** : $P < .01$

under nonflooded conditions. A severe reduction in the uptake of Ca occurred under nonflooded conditions as the pH increased.

The data in Table 28 also show that the application of Cu resulted in significant increases in the concentration and uptake of Ca by rice plants.

The influence of flooding, soil reaction(pH), and application of Cu on the concentration and uptake of K by rice plants grown on Lafitte muck is presented in Table 29. The data show that flooding the soil resulted in a significant decrease in the concentration of K in rice plants, but did not significantly influence the uptake of K.

The concentration of K in rice tissue was not significantly influenced by the pH levels alone, but was significantly influenced by the interaction of flooding and soil pH. Under flooded conditions, the concentration of K in the plants at pH levels ≤ 5.4 was significantly higher than at pH levels ≥ 5.9. No significant differences in the concentration of K in rice tissue were observed on the soil that was not flooded at all of the pH levels.

The uptake of K by rice plants depended on the soil pH levels and the interaction between pH and flooding.

The application of Cu to Lafitte muck resulted in a significant decrease in the concentration of K in rice tissue. A significant interaction occurred between pH

Table 29. The influence of flooding, soil reaction(pH), and application of Cu on the concentration and uptake of K by Saturn rice plants grown on Lafitte muck.

Treatments		Soil reaction (pH)							ANOV2/
		4.2	4.8	5.4	5.9	6.3	6.7	Mean	
					K concentration, %				
Flooded	No Cu	2.23	2.39	2.25	2.08	1.88	1.93	2.12	A **
	Cu 1/	2.02	2.10	2.14	1.99	1.97	1.82	2.01	B ns
	Mean	2.12	2.24	2.20	2.04	1.93	1.87	2.07	AB *
Nonflooded	No Cu	2.54	2.47	2.75	2.63	2.31	2.52	2.54	C *
	Cu	2.14	2.41	2.47	2.50	2.63	2.64	2.46	AC ns
	Mean	2.34	2.44	2.61	2.57	2.47	2.58	2.50	BC **
	pH mean	2.23	2.34	2.40	2.30	2.20	2.27	2.28	ABCns
	Cu mean	No Cu : 2.33		Cu : 2.24					
					K uptake, mg/pot				
Flooded	No Cu	85.8	93.7	89.0	89.3	70.5	68.0	81.0	A ns
	Cu	90.0	97.0	100.1	83.3	72.7	66.7	85.0	B **
	Mean	87.9	95.4	94.6	75.7	71.6	67.3	83.0	AB **
Nonflooded	No Cu	94.5	96.0	92.2	78.3	49.6	44.8	75.9	C ns
	Cu	89.6	99.4	95.0	83.6	64.1	46.8	79.8	AC ns
	Mean	92.0	97.7	93.6	81.0	57.0	45.8	77.9	BC ns
	pH mean	90.0	96.5	94.1	81.1	64.3	56.6	80.4	ABCns
	Cu mean	No Cu : 78.5		Cu : 82.4					

1/ Cu was applied at the rate equivalent to 5 ppm as $CuSO_4 \cdot 5H_2O$, 25% Cu.
2/ A : Flooding; B : Soil reaction; C : Cu treatments.
* : P < .05 ; ** : P < .01.

levels and Cu treatments on the concentration of K in rice tissue. The application of Cu resulted in a significant decrease in the concentration of K in rice tissue at pH of $\leq$5.9. However, at pH 6.3 and 6.7, the application of Cu tended to increase the concentration of K in rice tissue. The uptake of K by rice plants was not significantly influenced by the application of Cu.

Relationships as shown by simple correlation coefficients(r) and regression data between the concentration of Cu, Zn, Mn, Fe, P, Ca, and K and dry matter production, and the total chlorophyll content of "Y" leaves at soil pH levels $\leq$5.4 and $\geq$5.9 are presented in Table 30 and Figures 45-50.

At pH levels $\leq$5.4, significant positive relationships were observed between dry matter production and the concentration of Cu, r=0.778**, and the concentration of Fe in rice tissue, r=0.761**, as shown in Figures 45 and 46. A significant negative relationship was found between dry matter production and the concentration of K in rice tissue, r=0.859**.

At pH levels $\geq$5.9, significant positive relationships were found between the production of dry matter and the concentration of Fe, r=0.959**, and the concentration of P r=0.911**, as shown in Fegures 47 and 48. Significant negative correlations were found between the production of

Table 30. Relationships as shown by simple correlation coefficients(r) between the concentration of Cu, Zn, Mn, Fe, P, Ca, and K and dry matter production and the total chlorophyll content of "Y" leaves of rice plants at soil pH levels ≤ 5.4 and ≥ 5.9.

Concentration	Dry matter production		Chlorophyll content	
	At pH ≤ 5.4	At pH ≥ 5.9	At pH ≤ 5.4	At pH ≥ 5.9
	- - - - - - - r values		- - - - - - -	
Cu	0.778**	0.216	0.800**	0.199
Zn	0.049	-0.094	0.281	-0.058
Mn	-0.145	-0.541	0.092	-0.552
Fe	0.761**	0.959**	0.569	0.955**
P	0.086	0.911**	-0.220	0.877**
Ca	-0.178	-0.612*	0.008	-0.566
K	-0.859**	-0.764**	-0.682*	-0.709**

* : $P < .05$; ** : $P < .01$.

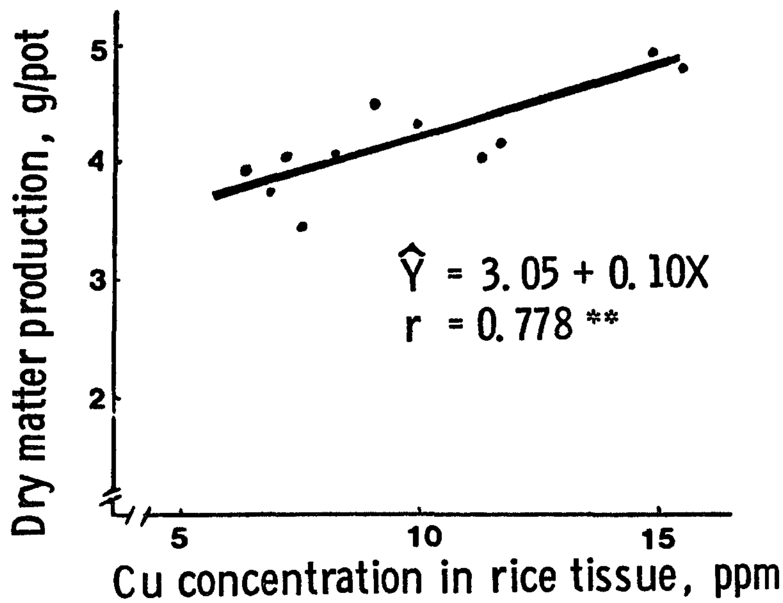

Figure 45. Relationship between dry matter production by rice plants and Cu concentration in rice tissue grown on Lafitte muck at soil pH levels ≤ 5.4. ** $P < .01$

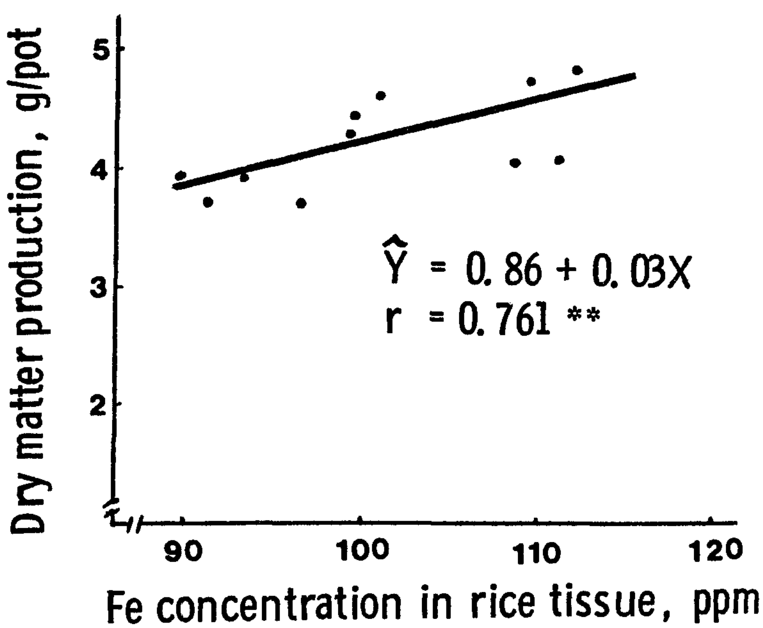

Figure 46. Relationship between dry matter production by rice plants and Fe concentration in rice tissue grown on Lafitte muck at soil pH levels ≤ 5.4. ** $P < .01$

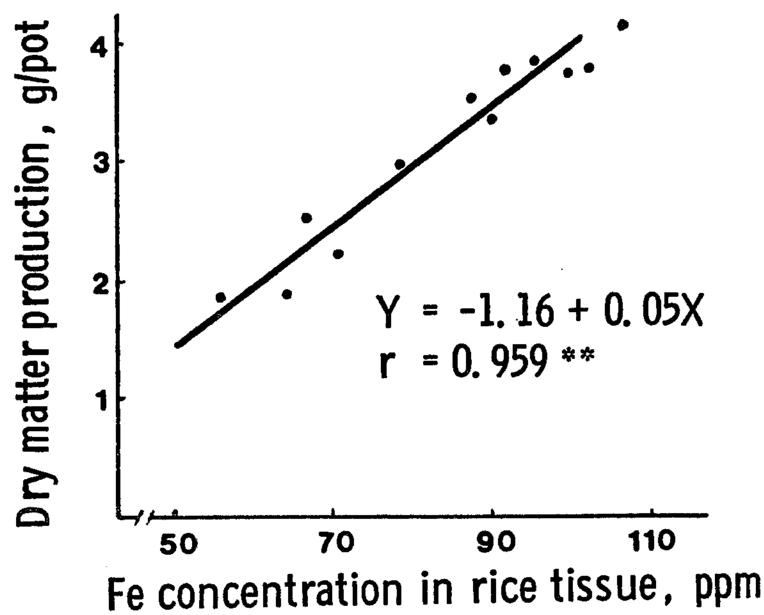

Figure 47. Relationship between dry matter production by rice plants and Fe concentration in rice tissue grown on Lafitte muck at soil pH levels ≥ 5.9. ** $P < .01$

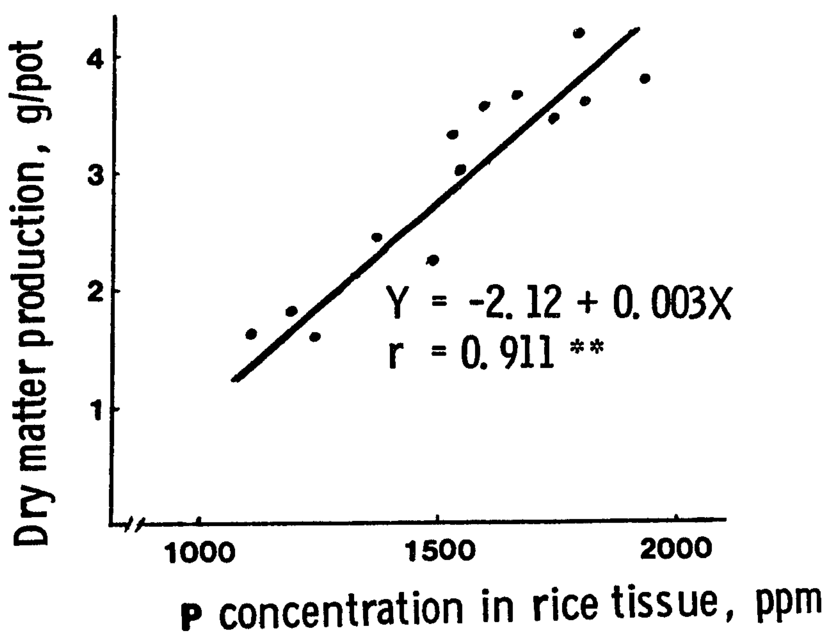

Figure 48. Relationship between dry matter production by rice plants and P concentration in rice tissue grown on Lafitte muck at soil pH levels ≥ 5.9. ** $P < .01$

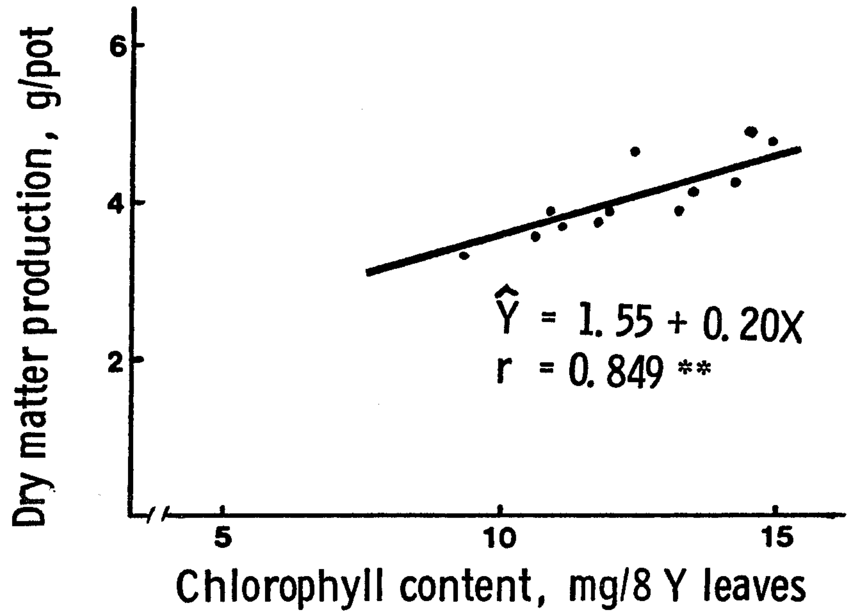

Figure 49. Relationship between dry matter production by rice plants and total chlorophyll content of "Y" leaves of rice plants grown on Lafitte muck at soil pH levels ≤ 5.4. ** $P < .01$

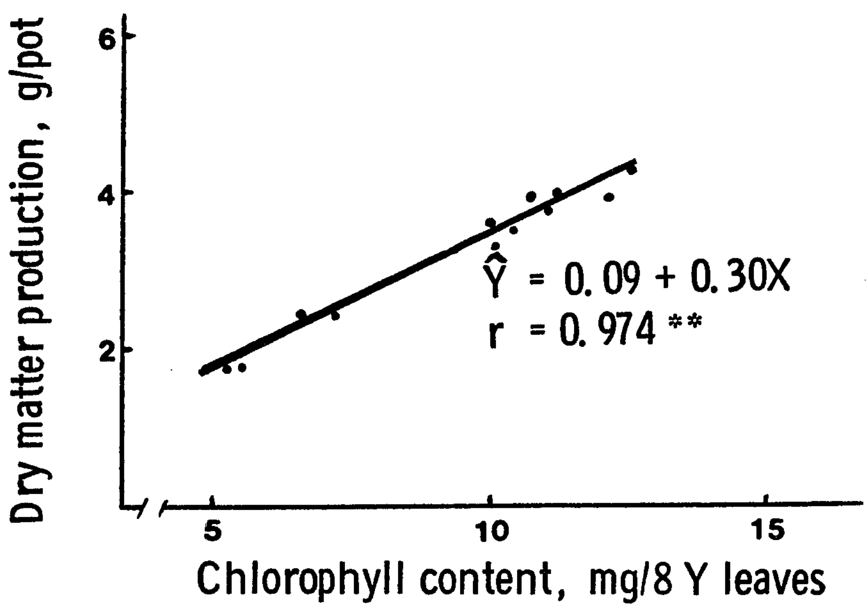

Figure 50. Relationship between dry matter production by rice plants and total chlorophyll content of "Y" leaves of rice plants grown on Lafitte muck at soil pH levels ≥ 5.9. ** $P < .01$

dry matter and the concentration of K, $r=-0.764^{**}$, and the concentration of Ca, $r=-0.612^{**}$.

The concentrations of Zn and Mn in rice tissue were not significantly related to the production of dry matter at either lower or higher pH levels.

The results obtained suggest that at the lower pH levels, the increase in the availability of Cu and Fe as a result of flooding and the application of Cu, may have been partly responsible for the increase in the amount of dry matter produced by rice plants. At the higher pH levels, the solubility of Fe and P was probably reduced and they became limiting in the growth of rice plants. Tissue concentrations of Fe and P of less than 70 and 1000 ppm, respectively, have been reported to be critical levels in rice at the tillering stage of plant development(Yoshida, et al.,1972). Lime-induced P deficiency at high pH levels has been reported by Helyar and Anderson (1974).

The data in Table 30 also show that at the lower pH levels, pH 4.2-5.4, the total chlorophyll content of "Y" leaves was significantly positively correlated with the concentration of Cu in rice tissue, $r=0.800^{**}$, and the total chlorophyll was significantly negatively correlated with the concentration of K, $r=-0.682^{*}$.

At the higher pH levels, pH 5.9-6.7, the concentrations of Fe and P were significantly positively correlated with the total chlorophyll content of leaves. The correlation coefficients(r) were 0.955** and 0.877**, respectively. A significant negative correlation was found between the concentration of K and leaf chlorophyll content, r=-0.709**.

The relationships between the production of dry matter and the total chlorophyll content of rice leaves at pH levels ≤ 5.4 and at pH levels ≥ 5.9 are presented in Figures 49 and 50. Total chlorophyll content of "Y" leaves was significantly positively correlated with the amounts of dry matter produced by rice plants on the soil with pH levels ≤ 5.4 and ≥ 5.9. The results obtained suggest that the increase in the leaf chlorophyll content may have been a significant factor in the increase in the production of dry matter by rice plants. The increased availability of Cu at pH levels ≤ 5.4, and the increased availability of Fe and P at pH levels ≥ 5.9 may have been responsible for increasing the leaf chlorophyll content, and also for increasing the production of dry matter by rice plants.

Relationships as shown by simple correlation coefficients(r) among the concentrations of Cu, Zn, Mn, Fe, P, Ca, and K in rice tissue at pH levels ≤ 5.4 are presented in Table 31. The concentration of Cu in rice plant tissue was significantly correlated with Fe concentration, r=0.594*. Statistically significant positive relationships were also found between concentrations of Zn and Mn, r=0.867**, Zn and Ca, r=0.861**, and Mn and Ca, r=0.626*. Statistically significant negative relationships were calculated between concentrations of Zn and P, r=-0.714**, Fe and K, r=-0.722**, and P and K, r=-0.880**.

Relationships as shown by simple correlation coefficients(r) among the concentrations of Cu, Zn, Mn, Fe, P, Ca, and K in rice tissue at pH levels $\geq$5.9 are presented in Table 32. The concentration of Cu in rice tissue was not significantly related to any of the other nutrients determined. Statistically significant positive correlations were found between concentrations of Mn and Zn, r=0.702**, Mn and Ca, r=0.838**, Mn and K, r=0.836**, Fe and P, r=0.875**, and Ca and K, r=0.798**. Significantly negative correlations were obtained between concentrations of Fe and Ca, r=-0.606*, Fe and K, r=-0.812**, P and K, r=-0.738**, and P and Ca, r=-0.767**.

Relationships as shown by simple correlation coefficients(r) between concentrations of Cu, Zn, Mn, Fe, P, Ca, and K and the uptake of these elements at pH levels $\leq$5.4 are presented in Table 33. The uptake of Cu by rice plants was significantly correlated with the concentration of Cu, r=0.987**, and with the concentration of Fe,

$r=0.655^{*}$. The uptake of Zn was significantly correlated with the concentrations of Cu, $r=0.839^{**}$, Zn, $r=0.815^{**}$, and with Mn, $r=0.617^{*}$. Highly significant positive correlations were found between the uptake of Mn by rice and the concentrations of Zn, 0.847^{**}, and Mn, $r=0.810^{**}$. Highly significant correlations were calculated between the uptake of Fe by rice plants and the concentrations of Cu, $r=0.727^{**}$, Fe, $r=0.919^{**}$, and K, $r=-0.859^{**}$.

Significant negative relationships were found between the uptake of P by rice and the concentrations of P, $r=-0.788^{**}$, Ca, $r=-0.763^{**}$, and K, $r=-0.859^{**}$. The uptake of Ca by rice plants was significantly positively correlated with concentrations of Cu, $r=0.774^{**}$, Zn, $r=0.859^{**}$, and Ca, $r=0.853^{**}$, and was significantly negatively correlated with the concentration of P, $r=-0.778^{**}$. The uptake of K by rice was significantly correlated with Cu, Zn, Mn, P, and Ca.

Relationships as shown by simple correlation coefficients(r) between the concentrations of Cu, Zn, Mn, Fe, P, Ca, and K and the uptakes of these elements by rice plants at pH levels ≥ 5.9 are presented in Table 34. The concentration of Fe was significantly correlated with all of the measured nutrients taken up by the plants with the exception of Mn. The P concentration in rice tissue was significantly correlated with all measured

Table 31. Relationships as shown by simple correlation coefficients(r) among the concentrations of Cu, Zn, Mn, Fe, P, Ca, and K in Saturn rice tissue at soil pH levels ≤ 5.4.

Variables	Zn	Mn	Fe	P	Ca	K
	- - - - - - -	r values	- - - - - -			
Cu	0.489	0.136	0.594*	-0.417	0.380	-0.441
Zn		0.867**	-0.011	-0.714**	0.861**	0.324
Mn			-0.207	-0.467	0.626*	0.406
Fe				0.143	-0.101	-0.722**
P					-0.880**	-0.451
Ca						0.561

* : P < .05; ** : P < .01.

Table 32. Relationships as shown by simple correlation coefficients(r) among the concentrations of Cu, Zn, Mn, Fe, P, Ca, and K in Saturn rice tissue at soil pH levels ≥ 5.9.

Variables	Zn	Mn	Fe	P	Ca	K
	- - - - - -		r values	- - - - - - -		
Cu	0.431	0.501	0.221	-0.024	0.509	0.176
Zn		0.702*	-0.114	0.005	0.472	0.572
Mn			-0.570	-0.561	0.838**	0.836**
Fe				0.875**	-0.606*	-0.812**
P					-0.767**	-0.738**
Ca						0.798**

* : P <.05; ** : P <.01.

Table 33. Relationships as shown by simple correlation coefficients(r) between concentrations of Cu, Zn, Mn, Fe, P, Ca, and K and the uptakes of these elements at soil pH levels ≤ 5.4.

Concentration	Uptake						
	Cu	Zn	Mn	Fe	P	Ca	K
	- - - - - r values - - - - - -						
Cu	0.987**	0.839**	0.561	0.727**	0.168	0.774**	0.686*
Zn	0.386	0.815**	0.847**	-0.008	0.498	0.859**	0.751**
Mn	0.064	0.617*	0.810**	-0.192	-0.421	0.553	0.605*
Fe	0.655*	0.429	0.175	0.919**	0.555	0.314	0.141
P	-0.300	-0.491	-0.408	0.132	-0.788**	-0.778**	-0.625*
Ca	0.248	0.558	0.531	-0.199	-0.763**	0.853**	0.663*
K	-0.554	-0.242	0.006	-0.859**	-0.859**	0.185	0.156

* : P <.05; ** : P <.01.

Table 34. Relationships as shown by simple correlation coefficients(r) between concentrations of Cu, Zn, Mn, Fe, P, Ca, and K and the uptakes of these elements at soil pH levels ≥ 5.9.

Concentration	Uptake						
	Cu	Zn	Mn	Fe	P	Ca	K
	- - - - - - r values - - - - - -						
Cu	0.808**	0.440	0.693*	0.245	0.138	0.415	0.392
Zn	0.259	0.461	0.628*	-0.124	-0.059	0.074	0.318
Mn	0.012	-0.085	0.356	-0.538	-0.537	-0.356	-0.171
Fe	0.730**	0.769**	0.519	0.984**	0.943**	0.926**	0.769**
P	0.533	0.809**	0.515	0.884**	0.952**	0.832**	0.788**
Ca	-0.031	-0.278	0.093	-0.589*	-0.662*	-0.405	-0.314
K	-0.357	-0.376	-0.042	-0.802**	0.781**	-0.629*	-0.343

* : P < .05; ** : P < .01.

nutrients taken up with the exceptions of Cu and Mn.

The effects of applications of Cu and Zn on the yield of Saturn rice plants grown on Crowley silt loam are presented in Table 35. The data show that Cu and Zn applied individually or in combination did not significantly influence the yield of Saturn rice in each of the years or as an average of the two years. However, slightly higher yields were obtained on plots that received Cu and Zn in each of the two years.

The effects of applications of Cu and Zn on the concentration of Cu, Zn, Mn, and Fe in Saturn rice-leaf tissue grown on Crowley silt loam are presented in Table 36. The application of Cu resulted in an significant increase in the concentration of Cu and Zn in the rice-leaf tissue in each of the years or as an average of the years. The application of Zn significantly increased the Zn concentration in leaves, but did not significantly influence the Cu concentration in the rice leaves. Relatively low concentrations of Cu in leaf tissue were obtained on plots that received an application of Zn.

The Cu and Zn treatments had no significant influence on the concentration of Mn and Fe in rice leaves. A small but consistent decrease in the Mn and Fe concentration of rice leaves was obtained on the soil that received applied Cu and Zn.

Table 35. The effects of applications of Cu and Zn on yield of Saturn rice plants grown on Crowley silt loam at the Rice Experiment Station, Crowley, Louisiana, 1979-1980.

Treatments	Yield 3/ avg. 4 reps.		
	1979	1980	Two year Avg.
	- - - - - - kg/ha - - - - - -		
Check	5,418	2,642	4,030
Cu 1/	5,574	2,621	4,098
Zn 2/	5,563	2,710	4,137
Cu 1/ + Zn 2/	5,757	2,758	4,258
LSD, 5%	ns	ns	ns

1/ Cu was applied at a rate equivalent to 0.44 kg/ha of metallic Cu as Cu chelate, 13% Cu.

2/ Zn was applied at a rate equivalent to 1.75 kg/ha of metallic Zn as Zn chelate, 14.2% Zn.

3/ Yield was adjusted to 12% moisture.

Table 36. The effects of applications of Cu and Zn on the concentrations of Cu, Zn, Mn, and Fe in Saturn rice-leaf tissue grown on Crowley silt loam at the Rice Experiment Station, Crowley, Louisiana, 1979-1980.

Leaf tissue concentrations 1/	Year	Treatments				LSD,5%
		Check	Cu 2/	Zn 3/	Cu 2/ + Zn 3/	
		- - - - ppm - - - -				
Cu	1979	6.95	8.25	6.08	7.37	1.62
	1980	4.62	5.12	4.50	4.88	0.50
	Two year avg.	5.78	6.69	5.29	6.12	0.82
Zn	1979	17.9	19.3	19.2	20.8	1.1
	1980	12.9	15.1	16.9	16.8	1.0
	Two year avg.	15.4	17.2	18.0	18.8	0.7
Mn	1979	289	272	259	276	ns
	1980	360	329	334	340	ns
	Two year avg.	325	300	296	308	ns
Fe	1979	93	90	85	85	ns
	1980	110	94	95	95	ns
	Two year avg.	101	92	90	90	ns

1/ Concentrations were measured in "Y" leaves sampled at first joint.

2/ Cu was applied at a rate equivalent to 0.44 kg/ha of metallic Cu as Cu chelate, 13% Cu.

3/ Zn was applied at a rate equivalent to 1.75 kg/ha of metallic Zn as Zn chelate, 14.2% Zn.

SUMMARY AND CONCLUSIONS

Investigations were conducted in the greenhouse and in the laboratory to evaluate eight different chemical methods for extracting Cu from soils. Studies were also conducted to determine the influence of flooding periods on the extractabe Cu, Zn, Mn, and Fe in soils. The effects of different rates of applied Cu and the influence of flooding, soil pH, and application of Cu on the production of dry matter, and chemical composition of rice(*Oryza sativa* *L*. cultivar Saturn) plants were also investigated. An experiment was conducted in the field to determine the effects of applied Cu and Zn on grain yields and chemical composition of rice plants grown on Crowley silt loam (Typic Albaqualf).

The Cu contents of 19 air-dried and flooded soils were determined with the following eight extracting solutions: 0.5$\underline{N}$ HCl+0.05$\underline{N}$ $AlCl_3$, 0.5$\underline{N}$ HNO_3, 0.5$\underline{N}$ HCl, 0.1$\underline{N}$ HCl, 0.01M EDTA+1$\underline{N}$ $(NH_4)_2CO_3$, 0.01M EDTA+1$\underline{N}$ NH_4OAc, 0.005M DTPA-TEA, pH 7.3, and 1$\underline{N}$ NH_4OAc, pH 4.8. In general, the dilute acids removed consistently larger amounts of Cu from both air-dried and flooded soils than did the chelating agents or 1$\underline{N}$ NH_4OAc, pH 4.8. The EDTA+ $(NH_4)_2CO_3$ and EDTA+NH_4OAc extractants removed larger quantities of Cu than did the DTPA-TEA extractant.

Significantly smaller amounts of Cu were removed from air-dried and flooded soils with 1N NH_4OAc, pH 4.8 than with the other extractants.

Flooding the soils with distilled water for six weeks resulted in an increase in the pH of all of the soils. The DTPA-TEA extractant tended to remove smaller amounts of Cu from flooded soils than it did from air-dried soils. The dilute acids and EDTA extractants removed significantly larger amounts of Cu from flooded samples than air-dried samples in five of 19 soils.

In general, 1N NH_4OAc, pH 7.0 extractable Ca, Mg, and K were significantly correlated with Cu extracted from both air-dried and flooded soils with eight extractants. The extractable Cu was not significantly related to the pH or organic matter content of soils.

A significant quadratic relationship was found between dry matter production and soil pH. No significant relationships were found between dry matter production and Cu extracted from air-dried and flooded soils with the eight extractants.

The DTPA-TEA, pH 7.3, 0.1N HCl, and 1N NH_4OAc, pH 4.8 extractable Cu were significantly related to the concentration of Cu in rice tissue. The highest correlation coefficient(r=0.603**) was found between Cu concentration in rice tissue and DTPA-TEA extractable Cu from flooded soils. In general, the uptake of Cu by rice plants was significantly correlated with extractable Cu.

A significant negative correlation was found between the concentration of Cu in rice tissue and the organic matter content of soils. Each 1% increase in the organic matter content of the mineral soils resulted in a corresponding decrease of approximately 1 ppm in the concentration of Cu in rice tissue.

Multiple regressions consisting of extractable Cu in combination with soil organic matter content accounted for from 53.4% to 70.0% of the variations in the prediction of the concentration of Cu in rice tissue. Combinations of other soil chemical properties measured with extractable Cu did not significantly improve the predicability. The results suggest that any of the eight extractants could be used for determining soil-Cu if the content of soil organic matter was included in the regression analyses. Highly significant correlations were found among all of the extracting methods used for determining the contents of Cu from air-dried and flooded soils.

The effects of flooding periods on the extractable Cu, Zn, Mn, and Fe in five soils were determined. The DTPA-TEA extractable Cu and Zn decreased progressively as flooding periods were increased from 0 to six weeks. Flooding the soils resulted in a significant increase in

0.1N HCl extractable Cu in two of five soils, but tended to decrease in three soils. Flooding the soils increased DTPA-TEA extractable Mn and Fe. The increase in 0.1N HCl extractable Cu in Alligator clay and Falaya silt loam by flooding was attributed to the release of occluded Cu from Mn and Fe oxides.

The effects of different rates of applied Cu on dry matter production and chemical composition of rice plants grown on two soils were investigated. The Cu treatments did not significantly influence the production of dry matter on Myatt fine sandy loam. The application of 5 ppm of Cu to Lafitte muck resulted in a significant increase over the control in dry matter production. The concentration and uptake of Cu by rice grown on the two soils significantly increased with increasing rates of applied Cu. The application of 5 ppm of Cu to the Myatt soil resulted in a significant increase in the concentration of Zn in rice tissue. The Cu treatments did not significantly influence the concentration of Zn in the tissue of rice plants grown on Lafitte muck. The rates of Cu had no significant influence on the Mn concentration in rice tissue on the two soils, and on the Fe concentration in rice tissue on the Myatt soil. The application of 10 ppm of Cu to Lafitte muck resulted in a significant increase in the concentration of Fe in rice tissue.

The leaves of Saturn rice plants grown on Myatt fine sandy loam that received 10 and 20 ppm of applied Cu were chlorotic four weeks after seeding. Plant tissue analyses indicate that the chlorosis may have been due in part to low Zn:Cu and Fe:Cu ratios rather than to high Cu or low Zn and Fe concentrations in rice tissue. The plants in which Zn:Cu and Fe:Cu ratios were lower than approximately 3.0 and 5.0, respectively, exhibited chlorotic symptoms.

The application of increasing rates of Cu to the Myatt and Lafitte soils resulted in increases in the levels of soil-test Cu determined with the five extractants. Consistently higher percentages of applied Cu were recovered with all of the five extractants from Myatt fine sandy loam than from Lafitte muck. Quantities of Cu extracted with all of the five extractants from the soils that received an application of Cu were significantly related to the concentration of Cu in the plant tissue and uptake of Cu by rice plants. No one method appeared to be superior to another for extracting Cu from soils that received applied Cu.

The influence of flooding, soil reaction(pH), and application of Cu on dry matter production and chemical composition of rice plants grown on Lafitte muck was determined. Flooding resulted in significant increases in the production of dry matter, total leaf chlorophyll content, concentration of Cu, Fe, and P in rice tissue, and uptake of Cu, Fe, P, and Ca by rice plants. Flooding resulted in significant decreases in the concentration of Zn, Mn, Ca, and K in the plant tissue and uptake of Zn and Mn, but it did not significantly influence the uptake of K by rice plants.

Increasing the soil reaction of Lafitte muck from pH 4.8 to 6.7 by application of $CaCO_3$ resulted in significant decreases in the production of dry matter, total leaf chlorophyll content, and concentration and uptake of Cu, Zn, Mn, Fe, and P by rice plants. The concentration and uptake of Cu, Zn, Mn, and Fe by rice plants were significantly higher at pH 4.8 than at pH 4.2. The lower concentration and uptake of the heavy metals were thought to be due to direct competition by H^+ for absorption sites in the roots(Martell, 1957; Gupta, Chipman, and MacKay, 1970; Chaudhry and Loneragan, 1972). Significant interactions between flooding and soil pH were found on all of the variables measured with the exceptions of the concentrations of Zn and Ca.

The application of 5 ppm of Cu to Lafitte muck resulted in significant increases in the concentration and uptake of Cu, Fe, and Ca. The application of Cu significantly decreased the concentration of P and K, but significantly increased the uptake of P and K by rice plants. The application of Cu did not significantly influence the concentration of Zn and Mn in the plant tissue, but significantly increased the uptake of Zn and Mn by rice plants.

The concentration of Cu in rice tissue grown on soil without applied Cu tended to be lower under flooded conditions than under nonflooded conditions. When Cu was applied, a significantly higher concentration of Cu was found in rice plants grown under flooded conditions. The pH levels did not significantly influence the concentration of Cu in rice tissue grown on the soil without applied Cu. With applied Cu, significantly higher Cu concentrations were observed in the tissue at pH 4.8, 5.4, and 5.9 than at pH 4.2, 6.3, and 6.7.

The application of Cu to Lafitte muck resulted in a significant increase in the concentration of Zn in rice tissue at pH levels ≤ 5.4. Applied Cu resulted in a significant decrease in the concentration of Zn at pH 6.3 and 6.7. The application of Cu significantly decreased the concentration of K at pH levels ≥ 5.9 and significantly increased the concentration of K in rice tissue at pH 6.3 and 6.7.

The concentration of Cu in rice tissue was significantly correlated with the production of dry matter, total leaf chlorophyll content, and the uptake of Cu, Zn, Fe, Ca, and K by the plants at soil pH ≤ 5.4. At pH ≥ 5.9, the concentrations of Fe and P were significantly correlated with the production of dry matter, total leaf chlorophyll content, and the uptake of Zn, Fe, P, Ca, and K by rice plants. The total leaf chlorophyll content was significantly correlated with the production of dry matter by rice plants at the lower and higher pH levels. The results suggest that increasing the concentration of Cu at the lower pH levels and increasing the concentration of Fe and P at the higher pH levels were significant factors in increasing the chlorophyll content, the production of dry matter, and the nutrient uptake by rice plants on Lafitte muck.

Cu and Zn applied to Crowley silt loam, individually or in combination, did not significantly influence the grain yields under field conditions in each of the two years or as an average of the two years. However, higher yields were obtained on plots that received Cu in combination with Zn in each of the two years. The application of Cu resulted in significant increases in the concentrations of Cu and Zn in rice leaves. The application of Zn significantly increased the concentration of Zn, but it did not significantly influence the concentration of Cu in the rice leaves, The Cu and Zn treatments had no significant influence on the concentrations of Mn and Fe in rice leaves at the first joint stage of plant development.

The data obtained from laboratory, greenhouse, and field investigations indicate that there is not a critical need for supplemental Cu fertilization of rice on the mineral soils. The data suggest that Cu may be beneficial to rice growing on soils that contain more than approximately 4% of organic matter and less than 0.2 ppm of DTPA-TEA extractable Cu.

LITERATURE CITED

Agrawal, H. P., and D. C. Pandey. 1972. Effect of copper application on chlorophyll content of wheat leaves. Indian J. Agir. Sci. 42(3):230-232.

Anderssen, F. G. 1932. Chlorosis of deciduous fruit trees due to a copper deficiency. J. Pomol. 10:130-146.

Aoki, M. 1941. Studies on the behavior of phosphoric acid under paddy field condition. Part I. J. Sci. Soil and Manure, Japan. 15:182-202.

Aymond, H. J. 1972. The zinc nutrition of rice as influenced by flooding and applications of zinc, lime, and organic matter. Ph. D. dissertation. LSU., Baton Rouge, Louisiana.

Bandyopadhya, A. K., and M. Adhikari. 1968. Trace elements relationships in rice soils of West Bengal. Soil Sci. 105:244-247.

Berger, K. C., and P. F. Pratt. 1963. Advances in secondary and micronutrient fertilization. McVickar, et al.(ed). Fertilizer technology and usage. Soil Sci. Soc. of Amer. Madison. Wis.

Bergman, H. F., and W. E. Truran. 1937. Investigations on the effect of copper on the growth of cranberry vines. Mass. Agr. Exp. Sta. Bull. 339.

Bingham, F. T., and M. J. Garber. 1960. Solubility and availability of micronutrients in relation to phosphorus fertilization. Soil Sci. Soc. Amer. Proc. 24:209-213.

Bingham, F. T., A. L. Page, R. J, Mahler, and T. J. Ganje. 1976. Cadnium availability to rice in sludge-amended soil under "flooded" and "nonflooded" culture. Soil Sci. Soc. Amer. J. 40:715-719.

Bleeker, P., and M. P. Austin. 1970. Relationship between trace element content and other soil variable in some Papua- New Guinea soils as shown by regression analyses. Aust. J. Soil Res. 8:133-143.

Blevins, R. L., and H. F. Massey. 1959. Evaluation of two methods of measuring available soil copper and the effect of soil pH and extractable aluminum on copper uptake by plants. Soil Sci. Soc. Amer. Proc. 23:296-298.

Bostrom, K. 1967. Some pH-controlling redox reactions in natural waters. Adv. Chem. Ser. 67:286-311.

Bradley, D. B., and D. H. Sieling. 1953. Effect of organic anions and sugars on phosphate precipitation by iron and aluminum as influenced by pH. Soil Sci. 76: 175-180.

Brown, J. C., and C. D. Foy. 1964. Effect of Cu on the distribution of P, Ca, and Fe in barley plants. Soil Sci. 98:362-370.

Brown, J. C., and W. E. Jones. 1977. Fitting plants nutritionally to soils. II. Cotton. Agron. J. 69:405-409.

Brown, J. C., and J. Jurinak. 1964. Effect of liming on availability of Zn^{2+} and Cu^{2+}. Soil Sci. 93:170-173.

Brown, J. C., L. O. Tiffin, and R. S. Holmes. 1958. Carbohydrate and organic acid metabolism with ^{14}C distribution affected by copper in Thatcher wheat. Plant Physiol. 33:38-42.

Brupbacher, R. H., W. P. Bonner, and J. E. Sedberry, Jr. 1968. Analytical methods and procedures used in the Soil Testing Laboratory. La. Agr. Exp. Sta. Bull. 632.

Butler, P. C. 1957. A study of heavy metal complexing by soil organic matter and its effect on the uptake of heavy metals by plants. Ph. D. Dissertation. N. C. State College, Raleigh, N. C.

Camp, A. W. 1945. Zinc as a nutrient in plant growth. Soil Sci. 60:157-167.

Chang, S. C., and M. L. Jackson. 1958. Soil phosphorus fractionations in some representative soils. J. Soil Sci. 9:109-119.

Chapman, H. D., G. F. Liebig, and A. P. Vanselow. 1939. Some nutritional relationships as revealed by a study of mineral deficiency and excess symptoms on citrus. Soil Sci. Soc. Amer. Proc. 4:196-200.

Chaudhry, F. M., and J. F. Loneragan. 1970. Effects of nitrogen, copper, and zinc fertilizers on the copper and zinc nutrition of wheat plants. Aust. J. Agr. Res. 21:865-879.

Chaudhry, F. M., and J. F. Loneragan. 1972. Zinc absorption by wheat seedlings. II. Inhibition by hydrogen ions and by micronutrient cations. Soil Sci. Soc. Amer. Proc. 36:327-331.

Chaudhry, M. S., and E. O. McLean. 1963. Comparative effects of flooded and unflooded soil conditions and nitrogen application on growth and nutrient uptake by rice plants. Agron. J. 55:565-567.

Chaudhry, F. M., M. Sharif, A. Latif, and R. H. Qureshi. 1973. Zinc-copper antagonism in the nutrition of rice (Oryza sativa L.). Plant and soil. 38(3):573-580.

Cheng, K. L., and R. H. Bray. 1953. Two specific methods of determining copper in soil and plant material. Anal. Chem. 25:655-659.

Cheshire, M. V., P. C. DeKock, and R. H. E. Inkson. 1967. Factors affecting the copper content of oats grown in peat. J. Sci. Food Agr. 18:156-160.

Chino, M., and S. Mitsui. 1967. Effect of heavy metal excesses on the absorption, translocation, and distribution of ^{59}Fe in rice plants. The occurrence of heavy metal induced iron chlorosis in plants. I. J. Sci. Soil and Manure. Japan. 38:249-254.

Clark, F., D. C. Nearpass, and A. W. Sprecht. 1957. Influence of organic addition and flooding on iron and manganese uptake in rice. Agron. J. 48:586-589.

Cole, W. F. 1943. X-ray analysis of some soil colloids from Gingin, Western Australia. Soil Sci. 89:53-60.

Conn, E. E., and P. K. Stumpf. 1972. Outlines of biochemistry. 3rd ed. John Wiley & Sons, Inc. New York, N. Y. pp535.

Cope, J. T. Jr., and R. D. Rouse. 1973. Interpretation of soil test results. Soil testing and plant analysis. Walsh and Beaton(ed). Soil Sci. Soc. Amer. Madison, Wis.

Dakhore, R. C., M. S. Naik, and N. B. Das. 1963. Effect of copper on the uptake of minerals by wheat plants on Delhi soil. Indian J. Agr. Sci. 33:219-225.

Darst, X. C., and J. H. Reeves. 1968. Micronutrients - The "fertilizer shoe-nails". A close look at copper. Solutions. May-June, 1968. 26-31.

De, S. K., O. P. Singh, S. Ali, and P. C. Srivastava. 1974. Effect of ammonium salts on the adsorption of copper by soils at 30 °C. Indian J. Agr. Chem. 7(2):111-117.

DeKock, P. C., M. V. Cheshire, and A. Hall. 1971. Comparison of the effect of phosphorus and nitrogen on copper-deficient and -sufficient oats. J. Sci. Food Agr. 22(9):437-440.

DeMumbrum, L. E., and M. L. Jackson. 1956. Infrared absorption evidence on exchange reaction mechanism of copper and zinc with layer silicate clays and peats. Soil Sci. Soc. Amer. Proc. 20:334-337.

Dokiya, Y., N. Owa, and S. Mitsui. 1968. Comparative physiological study of iron, manganese, and copper absorption by plants. III. Interaction between Fe, Mn, and Cu on the absorption of the elements by rice and barley seedlings. Soil Sci. Plant Nutrition. 14(5):169-174.

Dolar, S. G., and Keeney. 1971. Availability of Cu, Zn, and Mn in soils - influence of soil pH, organic matter, and extractable P. J. Sci. Food Agr. 22:273-278.

Engler, R. H., and W. H. Patrick, Jr. 1975. Stability of sulfides of manganese, iron, zinc, copper, and mercury in flooded and nonflooded soil. Soil Sci. 119:217-221.

Eswarappa, H., M. S. Naik, and N. B. Das. 1969. Study of microbiological and chemical methods for the status of available copper and zinc in tropical soils. Indian J. Agr. Sci. 39(8):761-769.

Fiskell, J. G. A.. 1965. Copper. Methods of soil analysis. Part 2. Chemical and microbiological properties. Amer. Soc. Agron. No.9. 1078-1089.

Fiskell, J. G. A., and C. D. Leonard. 1967. Soil and root copper. Evaluation of copper fertilization by analysis of soil and citrus roots. J. Agr. Feed Chem. 15.350-353.

Fleming, G. A., and J. Delaney. 1961. Copper and nitrogen in the nutrition of wheat on cutaway peat. Irish J. Agr. Res. 1:81-82.

Follett, R. H., and W. L. Lindsay. 1970. Changes in DTPA -extractable zinc, iron, manganese, and copper in soils following fertilization. soil Sci. Soc. Amer. Proc. 35:600-602.

Follett, R. H., and W. L. Lindsay. 1971. Profile distribution of zinc, iron, manganese, and copper in Colorado soils. Tech. Bull. Colo. St. Univ. 110. pp 79.

Fretzch, K. 1958. Occurrence and significance of latent copper deficiency. Pfl. Krankh. 65:257-267.
Fertilizer technology and usage(1963) McVickar, et al.(ed). Soil Sci. Soc. Amer. pp 300.

Gambrell, R. P., R. A. Khalid, and W. H. Patrick, Jr. 1976. Physicochemical parameters that regulate mobilization and immobilization of toxic heavy metals. Proceeding of the specialty conference on dredging and its environmental effects, Mobile, Alabama. Amer. Soc. Civil Eng. New York. 418-434.

Gilbey, D. J., K. D. Greathead, and J. W. Cartrell. 1970. Copper requirements for south-eastern wheat belt. J. Agr. West Aust. 11:70-72.

Giordano, P. M., and J. J. Mortvedt. 1972. Rice response to Zn in flooded and nonflooded soil. Agron. J. 64:521-524.

Goodman, B. A., and M. V. Cheshire. 1976. The occurrence of copper-porphyrin complexes in soil humic acids. J. Soil Sci. 27(3):337-347.

Gotoh, S., and W. H. Patrick, Jr. 1972. Transformation of manganese in a waterlogged soil as affected by redox potential and pH. Soil Sci. Soc. Amer. Proc. 36:738-742.

Gotoh, S., and W. H. Patrick, Jr. 1974. Transformation of iron in a waterlogged soil as influenced by redox potential and pH. Soil Sci. Soc. Amer. Proc. 38:66-71.

Govindarajan, S. V., and H. G. Gopal Rao. 1964. Effect of micronutrients on crop response and quality in Mysore State. J. Indian. Soc. Soil Sci. 12:355-361.

Grimme, H. 1968. Adsorption of Mn, Co, Cu, and Zn to geothite in dilite solutions. Z. Pfl. Bodenk. 121:58-65.

Grewal, J. S., D. R. Bhumbla, and N. S. Randhawa. 1969. Available micronutrient status of Punjab, Haryana, and Himachal soils. J. Indian Soc. Soil Sci. 17:27-31.

Grewal, J. S., C. Lal, and N. S. Randhawa. 1969. Evaluation of different methods for the determination of available copper in soils of Ludhiana. Indian J. Agr. Sci. 39(8):877-885.

Gupta, U. C., E. W. Chipman, and D. C. MacKay. 1970. Influence of manganese and pH on chemical composition, bronzing of leaves, and yield of carrots grown on acid sphagnum peat soil. Soil Sci. Soc. Amer. Proc. 34:762-764.

Gupta, U. C., L. B. McLeod. 1970. Response to copper and optimum levels in wheat, barley, and oats under greenhouse and field conditions. Can. J. Soil Sci. 50:373-378.

Gupta, S. K., G. P. Verma, and T. A. Singh. 1969. Effect of graded doses of phosphate on uptake of micronutrients. J. Indian Soc. Soil Sci. 17:477-482.

Harmer, P. M. 1945. Studies on the effect of copper sulfate applied to organic soil on the yield and quality of several crops. Soil Sci. Soc. Amer. Proc. 10: 284-294.

Helyar, K. R., and A. J. Anderson. 1974. Effect of calcium carbonate on the availability of nutrients in an acid soil. Soil Sci. Soc. Amer. Proc. 38:341-346.

Hem, J. D. 1972. Chemistry and occurrence of cadnium and zinc in surface water and ground water. Water Resources Res. 8(3):661-679.

Henrikson, A., and H. L. Jensen. 1958. Chemical and microbiological determinations of copper in soil. Acta. Agr. Scand. 8:441-469.

Hodgson, J. F., H. R. Geering, and W. A. Norvell. 1965. Micronutrient cation complexes in soil solution: Partition between complexed and uncomplexed forms by solvent extraction. Soil Sci. Soc. Amer. Proc. 29:665-669.

Honma, Y., and H. Hirata. 1974. Effect of heavy metals on the growth, yield, and Cd, Zn, and Cu contents of rice plants. J. Sci. Soil and Manure. Japan. 45:368-377.

Hosoda, K. 1942. Studies on improvement of soils aggravated by mine pollutions. V. Influences of copper, arsenic, zinc, lead, and iron upon rice yield, and the effects of improving materials against the damages. J. Sci. Soil and Manure. Japan. 16(11):459-466.

Hulagur, B. F., R. T. Dangarwala, and B. V. Mehta. 1975. Interrelationship among available zinc, copper, and phosphorus in soil. J. Indian Soc. Soil Sci. 20:17-33.

IRRI. 1969. Annual Rep. Int. Rice Res. Inst. Los Baños, Philippines.

IRRI. 1970. Annual Rep. Int. Rice Res. Inst. Los Baños, Philippines.

Ishizuka, Y., A. Tanaka, and O. Fujita. 1961. Inorganic nutrition of rice plants. 6. Effect of iron, manganese, and copper levels in culture solution on yields and chemical compositions of the plant. J. Sci. Soil and Manure. Japan. 32(3):97-100.

Islam, A., and M. A. Elahi. 1954. Reversion of ferric iron to ferrous iron under waterlogged conditions and its relation to available phosphorus. J. Agr. Sci. 45:1-2.

Itohara, T., and T. Tateya. 1965. Studies of Cu injury to paddy rice. 1. Effects of a supply of Cu containing water for irrigation according to the plant growth stage. 2. Test to know in what manner paddy rice is injured by water supply containig Cu and how to migrate injuries. Tohoku Nogyo Kenkyn. No. 7. 49-54.

James, W. O., C. R. C. Heard, and G. M. James. 1944. On the oxidative decomposition of hexosediphosphate by barley. The role of ascorbic acid. New Phytol. 43:62-74.

Jamison, V. C. 1943. The effect of particle size of copper- and zinc-source materials and of excessive phosphates upon the solubility of copper and zinc in a Norfork fine sand. Soil Sci. Soc. Amer. Proc. 8:323-326.

Jenne, E. A. 1968. Controls on Mn, Fe, Co, Ni, Cu, and Zn concentrations in soils and water: The significant role of hydrous Mn and Fe oxides. Trace inorganic in water. Adv. Chem. 73. Amer. Chem. Soc., Washington, D. C. 337-387.

Jugsujinda, A. 1975. Growth and nutrient uptake by rice under controlled oxidation-reduction and pH conditions in a flooded soil. Ph. D. Dissertation. LSU., Baton Rouge, Louisiana.

Kahn, D. H. 1969. Response of sweet corn and rice to P, Zn, and $CaCO_3$ on acid soil of California. Soil Sci. 108:424-428.

Kanwar, J. S. 1954. Influence of organic matter on copper fixation. J. Indian Soc. Soil Sci. 2:73-80.

Karim, H., J. E. Sedberry, Jr., and B. J. Miller. 1976. The profile distribution of total and DTPA-extractable Cu in selected soils in Louisiana. Commun. in Soil Sci. and Plant Analysis. 7(5):437-452.

Kausar, M. A., F. M. Chaudhry, A. Rashid, A. Latif, and S. M. Alam. 1976. Micronutrient availability to cereals from calcareous soil. 1. Comparative Zn and Cu deficiency and their mutual interaction in rice and wheat. Plant and Soil. 45(2):397-410.

Khalid, R. A., W. H. Patrick, Jr., and R. D. DeLaune. 1977. Phosphorus sorption characteristics of flooded soils. Soil Sci. Soc. Amer. J. 41:305-310.

Khan, A. 1979. Distribution of DTPA-extractable Fe, Zn, Cu in soil particle size fractions. Commun. in Soil Sci. and Plant Analysis. 10(9):1211-1218.

Kittrick, J. A. 1976. Control of Zn^{2+} in the soil solution by sphalerite. Soil Sci. Soc. Amer. Proc. 40:314-317.

Krauskopf,K. B. 1956. Factors controlling the concentrations of thirteen rare metals in sea-water. Geochim. Cosmochim. Acta. 9:1-32.

Kubowitz, F. 1937. Chemical composition of potato oxidase. Biochem. Ztschr. 292:221-229.

Kühn, H., and G. K. Judel. 1972. The effect of various applications of nitrogen, copper, and magnesium on oat yield. Z. Pfl. Bodenk. 131(2):97-108.

Lagunas Gil, R. 1964. Comparative study of different methods of extracting iron, copper, manganese from forrest soils. An.Edafol. Agrobiol. 23:81-90.

Lehman, D. S. 1963. Chelates in soils.- A symposium. Some principles of chelation chemistry. Soil Sci. Soc. Amer. Proc. 27:167-170.

Lin, C. K. 1946. Effect of oxigen and sodium thioglycolate on growth of rice. Plant physiol. 21:304-318.

Lindsay, W. L. 1972. Inorganic phase equilibria in soils. Micronutrients in Agriculture. Soil Sci. Soc. Amer. Madison, Wis. 41-57.

Lindsay, W. L., and E. C. Moreno. 1960. Phosphate phase equilibria in soils. Soil Sci. Soc. Amer. Proc. 24:177-182.

Lindsay, W. L., and W. A. Norvell. 1969. Equilibrium relationships of Zn^{2+}, Fe^{3+}, Ca^{2+}, and H^{+} with EDTA and DTPA in soils. Soil Sci. Soc. Amer. Proc. 33:62-68.

Lindsay, W. L., and W. A. Norvell. 1969. Development of a DTPA micronutrient soil test. Agron. Abstracts, Detroit, Michigan. pp 84.

Lindsay, W. L., and Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. Amer. J. 42.

Lipman, C. B., and G. MacKinney. 1931. Proof of the essential nature of copper for higher green plants. Plant Physiol. 6:593-599.

Locascio, S. J., P. H. Everett, and J. G. A. Fiskell. 1968. Effects of phosphorus sources and copper rates on water melons. Proc. Amer. Soc. Hort. Sci. 92:583-589.

Lucas, R. E. 1945. The effect of the addition of sulfates of copper, zinc, and manganese on the absorption of these elements by plants grown on organic soils. Soil Sci. Soc. Amer. Proc. 10:269-274.

Lucas, R. E. 1946. Chemical and physical behavior of copper in organic soils. Soil Sci. 66:119-129.

Lucas, R. E., and F. J. Davis. 1961. Relationship between pH values of organic soils and availabilities of 12 plant nutrients. Soil Sci. 92:177-182.

Lundblad, K., O. Svanberg, and P. Ekman. 1949. The availability and fixation of copper in Swedish soils. Plant and Soil. 1:277-302.

Lutz, J. A. Jr., C. F. Genter, and G. W. Hawkins. 1972. Effect of soil pH on element concentration and uptake by maize: II. Cu, B, Zn, Mn, Al, and Fe. Agron. J. 64:583-585.

Lyman, C., and L. A. Dean. 1942. Zinc deficiency of pineapples in relation to soil and plant composition. Soil Sci. 54:315-324.

Mahapatra, I. C. 1966. Soil phosphate transformations under various soil-water conditions. Ph.D. Dissertation. Louisiana State Univ., Baton Rouge, La.

Martell, A. E. 1957. The chemistry of metal chelates in plant nutrition. Soil Sci. 84:13-26.

Martens, D. C. 1968. Plant availability of extractable boron, copper, and zinc as related to selected soil properties. Soil Sci. 106:23-28.

McBride, M. B. 1976. Exchange and hydration properties of Cu^{2+} on mixed-ion Na^{+}-Cu^{2+} smectites. Soil Sci. Soc. Amer. J. 40(3):452-456.

McBride, M. B., and M. M. Mortland. 1974. Copper(II) interactions with montmorillonite: Evidence from physical methods. Soil Sci. Soc. Amer. Proc. 38(3):408-415.

McLaren, R. G., and Crawford. D. W. 1973. Studies on soil copper. I. The fractionation of Cu in soils. J. Soil Sci. 24(2):172-181.

Mehlich, A., and S. S. Bowling. 1975. Advances in soil test methods for copper by atomic absorption spectrophotometry. Commun. in Soil Sci. and Plant Analysis. 6(2):113-128.

Mehrotra, O. N., and H. K. Saxena. 1967. Responses of important crops to trace elements in Uttar Pradesh. Indian J. Agron. 12:186-192.

Mercer, E. R., and J. L. Richmond. 1970. Fate of nutrients in soil: Copper. Letcombe laboratory report. pp 9.

Misra, S. G., and R. C. Tiwari. 1966. Retention of applied Cu^{2+} by soils. Effect of carbonate, organic matter, base saturation, and unsaturation. Plant and Soil. 24:54-62.

Mitsui, S. 1954. Inorganic nutrition, fertilization, and soil amelioration for lowland rice. Yokendo Ltd. Tokyo.

Moore, D. P., M. E. Harward, D. D. Mason, R. J. Harder, W. L. Loth, and W. A. Jackson. 1957. An investigation of some of the relationships between copper, iron, and molibdenum in the growth and nutrition of lettuce: II. Response surfaces of growth and accumulations of Cu and Fe. Soil Sci. Soc. Amer. Proc. 21:65-74.

Mortensen, J. R. 1963. Complexing of metals by soil organic matter. Soil Sci. Soc. Amer. Proc. 27:179-183.

Motomura, S. 1969. Dynamic behavior of ferrous iron in paddy soils. Japan Nat. Inst. Agr. Sci. Ser. B. 21:1-114.

Neelakantan, V., and B. V. Mehta. 1961. Evaluation of methods of measuring availble copper in soils of Kaira District(Gujarat). J. Indian Soc. Soil Sci. 9:293-297.

Neelakantan, V., and B. V. Mehta. 1962. Distribution of copper in typical soil profiles of Gujarat. Indian J. Agr. Sci. 32:39-46.

Neish, A. C. 1939. Studies on chloroplasts: II. Their chemical composition and the distribution of certain metabolities between the chloroplasts and the remainder of the leaf. Biochem. J. 33:300-308.

Ohki, K. 1975. Mn and B effects on micronutrients and P in cotton. Agron. J. 67:204-207.

Orth, O. S., G. C. Wickwire, and W. Z. Burge. 1934. Copper in relation to chlorophyll and hemoglobin formation. Science. 79:33-34.

Ozus, T., and J. J. Hanway. 1966. Comparisons of laboratory and greenhouse tests for N and P availability in soil. Soil Sci. Soc. Amer. Proc. 30:224

Patrick, W. H. Jr. 1964. Extractable iron and phosphorus in submerged soil at controlled redox potentials. Trans. Eight Cong. Soil Sci. Bucarest. Romania. 4:605-610.

Patrick, W. H. Jr., and C. N. Reddy. 1977. Chemical changes in rice soils. Lab. for Wetland Soils and Sediments. Center ofr Wetland Resources. LSU., Baton Rouge, Louisiana.

Payne, K., and W. F. Pickering. 1975. Water, Air, and Soil Polution. 5: 63-69.

Peech. M. 1941. Availability of ions in light sandy soils as affected by soil reaction. Soil Sci. 51:473-486.

Percival, G. P., D. Josselyn, and K. C. Beeson. 1955. Factors affecting the micronutrient element content of some forages in New Hampshire. New Hampshire Agr. Exp. Sta. Tech. Bull. 93.

Pesek, J. T. Jr. 1950. A study of soil colloid-Cu ion equilibria and their relations to the absorption of copper by plants. Ph. D. Dissertation. North Carolina State College, Raleigh, N.C.

Ponnamperuma, F, N. 1955. The chemistry of submerged soils in relation to the growth and yield of rice. Ph. D. Dissertation. Cornell Univ. Ithaca, N.Y.

Ponnamperuma, F. N. 1965. Dynamic aspects of flooded soils and the nutrition of the rice plant. The Mineral Nutrition of the Rice plants. John Hopkins Pres. Baltimore, Md.

Ponnamperuma, F, N. 1972. Chemistry of submerged soils. Adv. Agron. 24:29-95.

Ponnamperuma, F, N. 1977. Behavior of minor elements in paddy soils. IRRI Res. Papper Ser. No. 8.

Possingham, J. V. 1956. Mineral nutrition and amino acids in tomato. Aust. J. Biol. Sci. 9:539-551.

Primavesi, A. M., and A. Primavesi. 1970. Effect of the trace element copper on rice(<u>Oryza sativa</u>). Agrochimica. 14:490-495.

Reddy, C. N., and W. H. Patrick, Jr. 1977. Effect of redox potential on the stability of Zn and Cu chelates in flooded soils. Soil Sci. Soc. Amer. J. 41:729-732.

Redman, F. H., and W. H. Patrick, Jr. 1965. Effect of submergence on several biological and chemical soil properties. La. Agr. Exp. Sta. Bull. 592.

Reith, J. W. S. 1968. Copper deficiency in crops in north-east Scotland. J. Agr. Sci., Camb. 70:39-45.

Reuther, W. 1957. Copper and soil fertility. Soil Year Book. Agr. USDA. pp 128-135.

Reuther, W., and P. F. Smith. 1954. Symposium: Minor elements in relation to soil factors. Toxic effects of accumulated copper in Florida soils. Soil Sci. Soc. Florida Proc. 14:17-23.

Rhyu, K. Y. 1977. Effect of copper on the growth of rice and nutrient uptake. M.S. Thesis. Jeonbug National Univ. Jeonju, Korea.

Robertson, W. K., L. G. Thompson, and F. G. Martin. 1973. Manganese and copper requirements for soybeans. Agron. J. 64(4):641-644.

Rogers, L. H., and Chik-Hwa-Wu. 1948. Zinc uptake by oats as influenced by application of lime and phosphorus. Agron. J. 40:563-566.

Russell, E. W. 1961. Soil conditions and plant growth. Longman, Green and Co. Ltd. London. pp 688.

Safaya, N. M. 1976. Phosphorus-zinc interaction in relation to absorption rates of phosphorus, zinc, copper, manganese, and iron in corn. Soil Sci. Soc. Amer. J. 40:719-722.

Salardini, A. A., and L. S. Murphy. 1977. Effects of iron applications on DTPA-extractable soil micronutrients. Soil Sci. 124(4):219-225.

Sanchez, P. A., and A. M. Briones. 1973. Phosphorus availability of some Philippines rice soils as affected by soil and water management practice. Agron. J. 65:226-228

Sanchez, I., and G. F. Lee. 1973. Sorption of copper on Lake Monona sediments. Effect of NTA on copper release from sediments. Water Resources Res. 7:587.

Schmid, W. E., H. P. Haag, and E. Epstein. 1965. Absorption of zinc by excised barley roots. Physiologia Pl. 18:860-869

Schnitzer, M., and S. I. M. Skinner. 1965. Organo-metallic interactions in soils: 4. Carboxyl and hydroxyl groups in organic matter and metal retention. Soil Sci. 99:278-284.

Seatz, L. F., A. J. Sterges, and J. C. Kramer. 1959. Crop response to zinc fertilization as influenced by lime and phosphorus application. Agron. J. 51:457-459.

Sedberry, J. E. Jr., B. J. Miller, and M. B. Said. 1978. An evaluation of chemical methods for extracting zinc from soils. Commun. in Soil Sci. and Plant Analysis. 10(4):689-701.

Sedberry, J. E. Jr., F. J. Perterson, F. E. Wilson, A. L. Nugent, R. M. Engler, and R. H. Brupbacher. 1971. Effect of zinc and other elements on the yield of rice and nutrient content of rice plants. La. Exp. Sta. Bull. 653.

Sedberry, J. E. Jr., F. J. Peterson, F. E. Wilson, D. B. Mengel, S. D. Maika, P. E. Schilling, and R. H. Brupbacher. 1980. Influence of soil reaction and zinc applications on yields and zinc contents of rice plants. La. Agr. Exp. Sta. Bull. 724.

Senewiratne, S. T., and D. S. Mikkelsen. 1961. Physiological factors limiting growth and yield of Oryza sativa under unflooded conditions. Plant and Soil. 14:127-146.

Shapiro, R. E. 1958. Effect of flooding on availability of phosphorus and nitrogen. Soil Sci. 85:190-197.

Shapiro, R. E. 1958. Effect of organic matter and flooding on availability of soil and synthetic phosphates. Soil Sci. 85:267-272.

Shuman, L. M. 1979. Zinc, manganese, and copper in soil fractions. Soil Sci. 127(1):10-17.

Sinha, H., and K. P. Singh. 1966. Copper status of Bihar soils. J. Agr. Res., Ranchi Univ. 1:39-46.

Sommer, A. L. 1931. Copper as an essential for plant growth. Plant Physiol. 6:339-345.

Spencer, W. F. 1966. Effect of copper on yield and uptake of phosphorus and iron by citrus seedlings grown at various phosphorus lebels. Soil Sci. 102:296-299.

Sreedharan, C., and C. M. George. 1969. Effect of micronutrients on paddy in a red loam soil of Karala (India). Agr. Res. J. Karala. 7:61-66.

Stevenson, F. J., and M. S. Ardakani. 1972. Organic matter reactions involving micronutrients in soils. Micronutrients in Agriculture. Soil Sci. Soc. Amer. Inc. Madison, Wis. p79-114.

Stotz, E. H., C. J. Harrer, and C. G. King. 1937. The chemical nature of "ascorbic acid oxidase". Science. 86:35

Tanaka, A., and S. Yoshida. 1970. Nutritional disorders of the rice plant in Asia. Int. Rice. Res. Inst. Tech. Bull. 10.

Tiwari, R. C., and B. M. Kumar. 1976. Effect of fertilizers on the availability of native copper and zinc in different soils. Fert. Technology. 13(1):30-33.

Tobia, S. K., and A. S. Hanna. 1958. Effect of copper sulfate added to irrigation water on the copper status of Egyptian soils: Amount of copper retained by soils. Soil Sci. 85:302-306.

Toth, S. J., A. L. Prince, A. Wallace, and D. S. Mikkelsen. 1948. Rapid quantitative determination of eight elements in plant tissue by a systematic procedure involving a flamephotometer. Soil Sci. Soc. Amer. Proc. 19:477-481.

Trieweiler, J. F., and W. L. Lindsay. 1969. EDTA-ammonium carbonate soil test for zinc. Soil Sci. Soc. Amer. Proc. 33:49-53.

Truog, E. 1946. Soil reaction influence on availability of plant nutrients. Soil Sci. Soc. Amer. Proc. 11:305-308.

Tsutsumi, M., and A. Fujiwara. 1966. Growth and Cu uptake of rice and barley plants with varing copper supply. Tohoku J. Agr. Res. 17:101-107.

Ufkes, E. A., and M. B. McBride. 1978. The effect of organic acids on heavy metal adsorption on montmorillonite and hydrous alumina. Agronomy Res. Rep. Cornell Univ. Ithaca, N. Y. pp 30.

Uritani, I. 1975. Physiology of copper and zinc. The significance of minor elements on plant Physiology. ASPAC. 30-60.

Valencia, I. G. 1962. The effect of flooding on the availability of phosphorus and on the growth of lowland rice. Ph.D. Dissertation. Univ. of Wisconsin. Madison. Wis.

Walkey, A., and I. A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37:629-672.

Wallace, A. 1962. Metal chelates in plant nutrition. A decade of synthetic chelating agents in inorganic plant nutrition. UCLA. Ca. 105-112.

Wallace, A., R. T. Mueller, J. W. Cha, and G. V. Alexsander. 1974. Soil pH, excess lime, and chelating agent on micronutrients in soybeans and bush beans. Agron. J. 66:698-700.

Wallace, A., E. M. Romney, V. Q. Hale, and R. M. Hoover. 1969. Effects of soil temperature and Zn application on yields and micronutrient content of four crop species grown together in a glasshouse. Agron. J. 61:567-568.

Wear, J. I., and A. L. Sommer. 1948. Acid-extractable zinc of soils in relation to the occurrence of zinc deficiency symptoms of corn: A method of analysis. Soil Sci. Soc. Amer. Proc. 12:143-144.

Wear, J. I. 1956. Effect of soil pH and calcium on the uptake of zinc by plants. Soil Sci. 81:311-315.

Wei, L. S. 1959. The chemistry of soil copper. Dissertation Abstract. 19. 2712.

Willis, L. G., and J. R. Piland. 1936. The function of copper in soils and its relation to availability of iron and manganese. J. Agr. Res. 52:467-476.

Yates, M. G., and E. G. Hallsworth. 1963. Some effects of copper in the metabolism of nodulated subterranean clover. Plant and Soil. 19:265-284.

Yoshida, S. 1975. Minor element for rice. ASPAC. Food & Fert. Tech. Cent. Extention Bull. 52.

Yoshida, S., D. A. Forno, J. H. Cock, and K. A. Gomez. 1972. Laboratory Manual for Physiological Studies of Rice. 2nd ed. IRRI.

Younts, S. E. 1964. Response of wheat to rates, dates of application and sources of copper and to other micronutrients. Agron. J. 56(3):266-269.

Younts, S. E., and R. P. Patterson. 1964. Copper-lime interaction in field experiment with wheat: Yield and chemical composition data. Agron. J. 56(2): 229-232.

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In January, 1978, he was granted a study leave and a fellowship from the Office of Rural Development, Suweon, Korea to pursue a doctoral study program at Louisiana State University. He is presently a candidate for the degree of Doctor of Philosophy in the Department of Agronomy.

EXAMINATION AND THESIS REPORT

Candidate: Moo Young EUN

Major Field: Agronomy

Title of Thesis: Influence of Flooding, Soil pH, Copper, and Zinc on Growth and Chemical Composition of Rice Plants

Approved:

Joe E. Sedberry, Jr.
Major Professor and Chairman

James G. Traynham
Dean of the Graduate School

EXAMINING COMMITTEE:

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Date of Examination:

November 12, 1980